

NORMATIVE DATA FOR THE UCAST-FW TEST OF APD IN CHILDREN

A thesis submitted in partial fulfilment of the requirements for the Degree

of Master of Audiology

in the University of Canterbury

by Justin Jie-Yin Yau

University of Canterbury

2018

Abstract

In subjects with normal auditory processing, the central auditory nervous system (CANS) supports the interpretation of poor speech signals by a process of intrinsic redundancy. Auditory closure is achieved, enabling the listener to ‘fill in the gaps’ when parts of the auditory signal are missing or partially unintelligible. Auditory processing disorder (APD) arises from a deficiency in CANS functionality, which reduces the individual’s ability to utilize intrinsic redundancies in listening circumstances with low extrinsic redundancy. Low redundancy speech tests (LRST) are a common method of evaluating an individual’s ability to fill in the missing components of speech signals. One such test is the University of Canterbury Adaptive Speech Test – Filtered Words (UCAST-FW; (McGaffin, 2007; O’Beirne, McGaffin, & Rickard, 2012; Rickard, Heidtke, & O’Beirne, 2013). While the UCAST-FW is sensitive enough to discriminate between children with and without APD (Rickard et al., 2013); the continuing maturation of the auditory cortex throughout childhood to adolescence means that clinical assessments of CAP must compensate for the effect of age on performance using correction factors (Wunderlich, Cone-Wesson, & Shepherd, 2006). The present study aimed to take steps towards clinical application for paediatric patients by investigating the impact of maturation on UCAST-FW as a function of age. 143 English speaking children, ranging from 6 to 12 years of age with normal hearing, were examined on their ability to discriminate speech items binaurally and monaurally on the UCAST-FW, along with questionnaires to provide information on potential predictor variables such as socioeconomic factors, ethnicity, and teacher evaluation of auditory performance (TEAP) score. Regression analysis found that participant age was the only variable to significantly predict binaural score ($p = 0.001$). A k-mean cluster analysis determined the age groupings that best defined the sample, and an ANOVA analysis of these groupings revealed a significant main effect of age on binaural scores $F(2,106) = 5.78, p = .004, \eta^2 = .098, 1 - \beta =$

.86. Post-hoc testing revealed significant differences between the oldest and middle cluster ($p = .026$) and between the oldest and youngest cluster ($p = .001$), but not between the middle and youngest cluster ($p = .19$). These results support the existing understanding of the development of the CANS in children from infancy to adolescence.

Acknowledgements

Thank you is an understatement for the gratitude I have for the hundreds of people who have so selflessly contributed to the completion of this dissertation, however a few in particular have instilled assurance, provision, and empathy in what has been a stressful yet equally rewarding season in my life.

Firstly to friends and family, thank you for your patience and unwavering sympathy from picking up the residual frustrations that I drop off at the end of a busy day's work in the unpredictably chaotic life of an unorganised thesis student.

Secondly to the many wonderful people who were involved in the pursuit of recruitment, I am grateful to the various school principals of Christchurch, Emma Parnell from the NZILBB, and Marie Lay my fellow colleague whom I have had the honour of working with in this co-dissertational alliance. Thank you for being so accommodating, compromising, and understanding to all the uncertainties that come along with such ambitious data-collection goals.

And finally, to Greg and Rebecca; you two have been paramount pillars of guidance and confidence in times of ambivalence. I implore you to continue championing the rangatahi of this incredible profession to pursue discovery in furthering the mission of helping people enjoy life through better hearing.

Now all glory to God, who is able, through His mighty power at work within us, to accomplish infinitely more than we might ask or think.

Ephesians 3:20 NIV

Contents

Abstract	iii
Acknowledgements	IV
Table of Contents	vi
List of Abbreviations	IX
List of Figures	XI
List of Tables	XIV

Chapter One	16
--------------------------	-----------

Introduction

1.1 General introduction	16
1.2 Central auditory processing	22
1.3 Maturation of central auditory nervous system (CANS)	25
1.4 Auditory Processing Disorder (APD)	27
1.5 Assessment of APD	28
1.6 Importance of Speech Audiometry	29
1.7 Open-set vs. closed-set speech audiometry response formats	31
1.8 Low redundancy, monaural filtered word speech tests	32
1.9 Non-adaptive vs. adaptive stimuli.....	37
1.10 University of Canterbury Adaptive Speech Test – Filtered Words (UCAST-FW)	39
1.11 Purpose for collection of normative data	43
1.12 Statement of the problem	45

Chapter Two	47
--------------------------	-----------

Methods

2.1 Recruitment.....	47
2.2 Participants.....	49
2.3 Equipment	52
2.4 Stimulus	54
2.5.1 Procedure	55
2.5.2 Audiometry	55
2.5.3 Tympanometry.....	56
2.5.4 Dissertational Alliance.....	56
2.5.5 UCAST-FW Closed Set.....	57

2.5.6 UCAMST-P	58
2.6 Statistical Analysis.....	59
Chapter Three	60
Results	
3.1 Missing Data	60
3.2 Trimming Outliers	61
3.3.1 TEAP score vs UCAST-FW performance	68
3.3.2 TEAP vs RE and LE	69
3.4 Age vs UCAST-FW performance.....	70
3.5 Overview of Analysis	72
3.6 Regression Analysis.....	69
3.7 Cluster Analysis	72
3.8.1 ANOVA	73
3.8.2 ANOVA Comparison Between Conditions	74
3.9 Post-Hoc Analysis of Reversal for the UCAST-FW.....	76
Chapter Four	82
Discussion	
4.1 Effects of participant age on UCAST-FW performance.....	82
4.2 Comparison of results with past research – Age vs UCAST-FW Score.....	83
4.3 Comparison of results with past research – Sample performance discrepancies	86
4.4 Comparison of results with past research - Potential predictor variables influence on CAP.....	88
4.5 Ear Differences	90
4.6 Effects on UCAST-FW Performance	91
Conclusion	
5.0 Conclusion	95
Limitations and Future Direction	
6.1 Recruitment and Participants	97
6.2 UCAST-FW Software.....	99
6.3 Testing Environment Limitations	100
6.4 Potential Fatigue and Examiner Effects.....	101

6.5 Lack of Statistical Power for True Normality	103
--	-----

References

References.....	105
-----------------	-----

Appendices

Appendix A: Ethical Approval	119
---	------------

Appendix B: Recruitment and Content	120
--	------------

B1 Information sheet & consent form given to each participant's parent/guardian prior to testing (page 1 of 4).....	120
---	-----

B2: Information sheet and assent form for 11-12 year old participants (page 1 of 2).....	124
--	-----

B3: Information sheet and assent form for 6-10 year old participants (page 1 of 2).....	126
---	-----

B4: Information sheet and consent form for the participant's teacher; utilised in preparation for testing in the primary schools (page 1 of 3).....	128
---	-----

B5: Advertisement email initiation to parents for Team Tamariki recruitment channel.....	131
--	-----

List of Abbreviations

APD Auditory Processing Disorder

CAP Central Auditory Pathway

LPF Low-Pass Filtered

CANS Central Auditory Nervous System

MGC Medial Geniculate Complex

AC Auditory Cortex

SOC Superior Olivary Complex

MSO Medial Superior Olivary

LSO Lateral Superior Olivary

MNTB Medial Nucleus of the Trapezoid Body

IC Inferior Colliculus

MGB Medial Geniculate Body

CAEP Cortical Auditory Evoked Potential

ADHD Attention Deficit Hyperactivity Disorder

BSA British Society of Audiology

A1 Primary Auditory Cortex

SSI Synthetic Sentence Identification

TCST Time Compressed Sentence Test

SRT Speech Recognition Threshold

PTA Pure Tone Thresholds

NAM Neighbourhood Activation Model

CVC Consonant-Vowel-Consonant

AT Auditory Thalamus

LRST Low Redundancy Speech Tests

UCAST-FW University of Canterbury Adaptive Speech Test – Filtered Words

DDT Dichotic Digits Test

CRWT Compressed and Reverberant Words Test

FPT Frequency Pattern Test

RGDT Random Gap Detection Test

NBILBB New Zealand Institute of Language, Brain, and Behaviour

SES Socio-Economic Status

TEAP Teacher Evaluation of Auditory Performance

UCAMPST-P University of Canterbury Paediatric Auditory-Visual Matrix Sentence Test

LPF Low-Pass Filtering

List of Figures

Figure 1. A simplified speech banana with an idealized 500 Hz filter overlying, illustrating the audibility of speech sounds under conditions of low-pass filtering.....	20
Figure 2. Schematic representation of the left (blue) and right (red) primary ascending connections of the human central auditory pathway, with nuclei initials labelled inside boxes. CN; cochlear nuclei; SOC, superior olivary complex; NLL nuclei of the lateral lemniscus; IC, inferior colliculus; MGB, medial geniculate body. The blue represents left side and the red represents the right. Adapted from Hackett (2009).	23
Figure 3. Interaction between intrinsic and extrinsic redundancy. Adapted from Krishnamurti (2007).	35
Figure 4. Mean data for each age group for the pitch and duration pattern, acquired from (Schochat & Musiek, 2006).	43
Figure 5. Parent questionnaire adapted from Dr. Brian O'Hara's APDQ 2017 version I: for parents and teachers of children aged 7 to 17 years old.	50
Figure 6. Teacher Evaluation of Auditory Performance (TEAP) Questionnaire (Purdy et al., 2002; M. Sharma and Purdy, 2013).	52
Figure 7: An example display of four-alternative picture choices for the acoustically..	57
Figure 8: Box plot displaying the LPF threshold of three different conditions for the UCAST-FW.....	61
Figure 9: Scatter plot displaying participant's TEAP mean score against their low-pass-filter threshold on the UCAST-FW under binaural condition with r-squared value.....	69

Figure 10: Scatter plot displaying participant's TEAP mean score against their low-pass-filter threshold on the UCAST-FW under the monaural right ear only condition.....	69
Figure 11: Scatter plot displaying participant's TEAP mean score against their low-pass-filter threshold on the UCAST-FW under the monaural left ear only condition.....	70
Figure 12: Scatter plot displaying participant's age in years against their low-pass-filter threshold on the UCAST-FW under the binaural condition.....	70
Figure 13: Scatter plot displaying participant's age in years against their low-pass-filter threshold on the UCAST-FW under the monaural right ear only condition.....	71
Figure 14: Scatter plot displaying participant's age in years against their low-pass-filter threshold on the UCAST-FW under the monaural left ear only condition.....	71
Figure 15: P-P Plot of Regression Standardized Residuals.....	74
Figure 16: Profile Plot showing change in mean UCAST-FW score as a function of number of reversals.....	80
Figure 17: Mean UCAST-FW scores (following 20 reversals at the working increment) for the right and left ears for Control and APD groups adapted from Rickard et al. (2013)	86
Figure 18: Bar graph showing mean distribution of binaural UCAST-FW score between binaural condition and the mean of monaural condition data set (RE and LE).....	92
Figure 19: Representative UCAST-FW adaptive tracks from three control participants (left hand panel) and three APD group participants (right hand panel). The 62.5% WUDR estimate is given by the Mean line, and the 99% confidence intervals, calculated on log-transformed data, are shown as dashed lines about the Mean adapted from (O'Beirne et al., 2012).....	94

List of Tables

Table 1. Table displaying scale and nominal co-variables presented with their respective missing data points.	60
Table 2. Quantitative details of data set pertaining to gender.....	62
Table 3. Quantitative details of data set pertaining to Ethnicity.....	62
Table 4. Quantitative details of data set pertaining to “Other” ethnicity.....	63
Table 5. Quantitative details of data set pertaining to responses for “Is English First Language?”.....	63
Table 6. Quantitative details of data set pertaining to responses for “If Not, Age Acquired”.....	64
Table 7. Quantitative details of data set pertaining to Additional Conditions/Services	64
Table 8. Quantitative details of data set pertaining to participant’s reading, writing, language, and behaviour against national standard at present	65
Table 9. Quantitative details of data set pertaining to participant’s reading, writing, language, and behaviour against national standard in the past	65
Table 10. Quantitative details of data set pertaining to participant’s reading, writing, language, and behaviour against national standard present vs past.....	66
Table 11. Quantitative details of data set pertaining to participant’s pure tone audiometry hearing screening results.....	66
Table 12. Quantitative details of data set pertaining to participant’s tympanometry results on right ear.....	66
Table 13. Quantitative details of data set pertaining to participant’s tympanometry results on left ear.....	67

Table 14. Quantitative details of data set pertaining to participant's otoscopy results on right ear.....	67
Table 15. Quantitative details of data set pertaining to participant's otoscopy results on left ear.....	67
Table 16. Table displaying continuous data co-variables presented through descriptive statistics.....	68
Table 17. Descriptive statistics for TEAP normative and clinical groups adapted from Keat (2016).....	68
Table 18. Despite the regression analysis utilising 71 participants, the cluster sample size increased to 115 because only performance on the binaural UCAST-FW data and age were required to perform this analysis.....	76
Table 19. Table showing mean distribution of binaural UCAST-FW score between the age groups of youngest, middle, and oldest.....	77
Table 20. Table showing mean distribution of monaural right ear UCAST-FW score between the age groups of youngest, middle, and oldest.....	78
Table 21. Table showing mean distribution of monaural left ear UCAST-FW score between the age groups of youngest, middle, and oldest.....	78
Table 22. Sample size for group clusters in post-hoc analysis of reversals for the UCAST-FW.....	79
Table 23. Mean UC MAST threshold scores for each age group. Values in brackets are standard deviations and all values are in Hertz. Adapted from McGaffin (2007)	84
Table 24. Comparison between mean and SD of UC MAST threshold scores for each age group and UCAST-FW results of cluster groupings in current study.....	84

Chapter One:

Introduction

1.1 General introduction

In the functional human auditory system, there is a high level of redundancy in the processing of spoken language which enables the listener to fill in missing speech information (termed “auditory closure”) despite a relative lack of clarity in the speech signal.

However, individuals with auditory processing disorder (APD) often find auditory closure to be difficult when the speech signal is degraded. APD is a condition that affects the ability to attend to, discriminate, recognise, or comprehend information presented via audition, despite the individual having normal peripheral hearing and functional cognitive abilities (Wilson, Heine and Harvey, 2004). The importance of sensitive and reliable diagnostic tests cannot be overstated, as children with undiagnosed or untreated APD are often labelled as having bad behaviour, or being disruptive, or inattentive. The lack of an accurate diagnosis may also result in a child being mislabelled as having attention deficit disorder or a cognitive deficit, thereby impacting the child’s self-confidence and self-efficacy.

This impairment of speech intelligibility occurs as a result of a disruption along the central auditory pathway (CAP) (Lagacé, Jutras and Gagné, 2010). However the site of disruption can occur at several positions along the auditory pathway, leading to heterogeneous presentations of the disorder. Therefore, despite close to fifty years of research into APD, a consensus on a simple definition has been difficult to achieve.

Those definitions described in the various position or consensus statements are, by necessity, multifaceted (e.g. British Society of Audiology, 2018). This “definition before diagnosis” dilemma can therefore make clinical investigations and interventions controversial and difficult while demand for APD services are rapidly growing (Bellis, 2003).

According to the British Society of Audiology (2018), individuals can be characterised as displaying traits of APD based several contributing factors: Poor perception of speech and non-speech sounds, observable behaviours of difficulty understanding speech in noise which may lead to frequent requests for repetition and mishearing speech. Furthermore, poor auditory memory may be displayed despite having a normal audiogram (peripheral hearing). Given clinical testing, the prognosis of the site of lesion often originates from impaired neural function which may include both the afferent and efferent pathways of the CANS. Finally, as APD is heterogeneous in presentation, co-morbidity with the disorder may be seen alongside other visual and cognitive delays such as language, speech, executive function, memory, emotion, and attention.

One commonly-used category of tests for the diagnosis of APD is the low-pass filtered (LPF) word tests. These low-redundancy tests challenge the central auditory nervous system (CANS) with their reduced high-frequency content, and aim to differentiate those with the disorder from those without it by administering low-redundancy speech samples which have been filtered to modify their frequency content. Reducing the extrinsic redundancies of the speech signal assesses the CANS’s ability to compensate for the degradation of speech by filling in missing components. These behavioural difficulties correlate with underlying neurophysiological and/or neuromaturational deficits which can be found in multiple neural pathways between the VIII nerve and

higher cortical areas. These pathways typically provide “intrinsic redundancy” to ensure the correct signals are being sent from the ear to the brain (Bamiou, Campbell and Sirimanna, 2006).

Intrinsic vs extrinsic redundancy

These CANS pathways assist with processes which include (but are not limited to) auditory sequencing ability, auditory blending, and auditory closure (Barrett, 1995). A functional CANS is very adept at using aspects of speech information such as frequency content, intensity, and temporal characteristics, with linguistic knowledge and context to allow the listener to piece together missing components to achieve auditory closure (Picard and Bradley, 2001). Considerable contributions of speech understanding performance occur within the pathway from the auditory nerve to the cortex, in both a hierarchical fashion as well as in parallel, irrespective of reductions in extrinsic redundancy (Sowell et al., 2003). This suggests that the intrinsic redundancies offered in functional CANS are resilient to reductions in extrinsic redundancy. However further degradation in speech signal may quite possibly affect an individual’s ability of auditory closure simply due to the human limitations of what the intrinsic mechanisms of the CANS can provide. The effect of low extrinsic redundancy is exaggerated and is more evident in those with APD given their low intrinsic redundancy. As a result of this underlying theory, a wide range of monaural-and binaural-low redundancy speech tests have been developed for the assessment of the functionality of the CANS.

Most tests that reduce redundancy by low-pass filtering speech have filtering fixed at a constant level, which makes them prone to ceiling and floor effects (Martin & Clark, 1977; Musiek, Geurkink, & Kietel, 1982; Willeford, 1977). This has been found to reduce sensitivity and specificity –for instance, when the cut-off frequency is set too low, even normal listeners struggle to interpret the filtered speech thereby posing challenges when distinguishing those with and without APD (Farrer and Keith, 1981). Unlike previous test versions, the University of Canterbury Adaptive Speech Test – Filtered Words (UCAST-FW; O’Beirne, McGaffin and Rickard, 2012; Rickard, Heidtke and O’Beirne, 2013) uses an adaptive procedure to counter ceiling and floor effects with the intent of improving sensitivity, specificity, and efficiency.

As each individual word used in filtered speech tests has different frequency content, filtering can have unequal effects on intelligibility from one word to another. A recent thesis by Gibbins (2018) aimed to compensate for these differences in word recognition performance in UCAST-FW. The goal was to create a method of normalisation that resulted in the same level of filtering creating similar word recognition performance irrespective of the spectral content of a particular word. This would further improve test validity of listener results being representative of auditory processing ability as oppose to confounding variation from test words that are too easier/difficult. As is demonstrated below in figure 1, phonemes in the English language vary in their spectral qualities and therefore when an idealized 500 Hz low-pass filter is overlaid; phonetic sounds such as *[mm]* are still audible under filtering whereas sounds like *[sh]* become cut off.

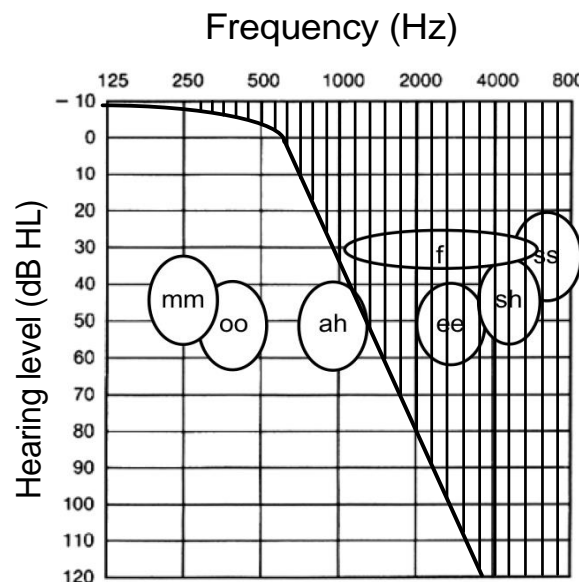


Figure 1. A simplified speech banana with an idealized 500 Hz filter overlying, illustrating the audibility of speech sounds under conditions of low-pass filtering.

Based on the knowledge of spectral variation, it can be assumed that CVC words like “mean” will still retain a substantial portion of its acoustic information for the listener due to its low frequency consonants which contribute heavily to the intelligibility. In comparison, a word like “shell” will have less information available due to its high frequency emphasis. It was shown that applying the same level of filtering show significantly different impacts on the word recognition performance respective to frequency content of the test word.

A novel method of normalisation was developed to alter the level of adaptive filtering for each word relative to the mean performance and the slope of the word list. For instance, if the next test item in the adaptive track was to be filtered at 700 Hz, and the word was “duck”, the normalisation process would look up the mean word recognition performance at 700 Hz, and determine what frequency the word “duck” needed to be filtered at to achieve the same mean level of word recognition performance across all test items that are filtered 700 Hz.

Psychometric data regarding these test items enabled a more homogenous word list with reduced inter-item variability. This has helped to create a diagnostic test with greater sensitivity to changes in individual performance based on auditory dysfunction as oppose to test item variability.

The New Zealand Ministries of Health and Education Expert Reference Group recognised the UCAST-FW as being suitable for use by audiologists in New Zealand, with the authors noting that it had acceptable test-retest reliability, established validity, demonstrated sensitivity and specificity, clinical acceptability, and published studies (APD Reference Group, 2017), but noted that it lacked normative data.

Such data would define the normal range of UCAST-FW results expected from children with attributes typical and representative of the general paediatric population in New Zealand. However given the sheer volume of participants required to meet normative sample sizes, this dissertation intends to lay the foundation for further data collection through future theses students to ultimately one day gather sufficient participant numbers to be deemed statistically sound normative data. The present study therefore aimed to quantify the significant maturational effect found between younger and older children participants when tested with the UCAST-FW (O'Beirne et al., 2012).

1.2 Central auditory processing

Central auditory processing (CAP) is responsible for transforming hearing into understanding by way of neurophysiological and neurochemical mechanisms that occur in the auditory system in response to acoustic stimuli from the peripheral auditory system (Liberalesso et al., 2012). Pragmatically, the role of CAP is to decipher spectral, spatial, and temporal acoustic signals into meaningful information required for communication. This requires a variety of processes by which the CANS is responsible for. Wilson, Heine, and Harvey (2004) provide a list of these processes; reauditorisation, subvocalisation, auditory closure, auditory blending, auditory separation, auditory projection, auditory sequencing ability, auditory memory span, discrimination for sound, auditory memory, localization of sound, awareness of sound, auditory attention and auditory attention span. The perception of sound ultimately depends on the extraction of meaningful information encoded in the activity of neurons in dozens of subcortical nuclei and cortical areas. This extraction process involves the integration of multiple segregated pathways responsible for transmitting specialized acoustic information from lower stages such as the cochlea up to high centres, including the medial geniculate complex (MGC), and the auditory cortex (AC) (Hackett, 2009).

At present, most of what is known about the subcortical auditory pathways derives from studies on non-primates such as bats, cats, and rodents (Aitkin, 1986). As equivalent studies in primates are limited, the principles of the auditory system at the subcortical level are commonly generalised across taxonomic groups, including humans (Fay, 2013).

Comparatively, the somatosensory and visual systems are significantly more straightforward than the exceptionally complex subcortical auditory pathways.

Figure 2 provides a simplified schematic of the main parallel and serial pathways that make up the complex network of connections between the auditory nuclei at different levels.

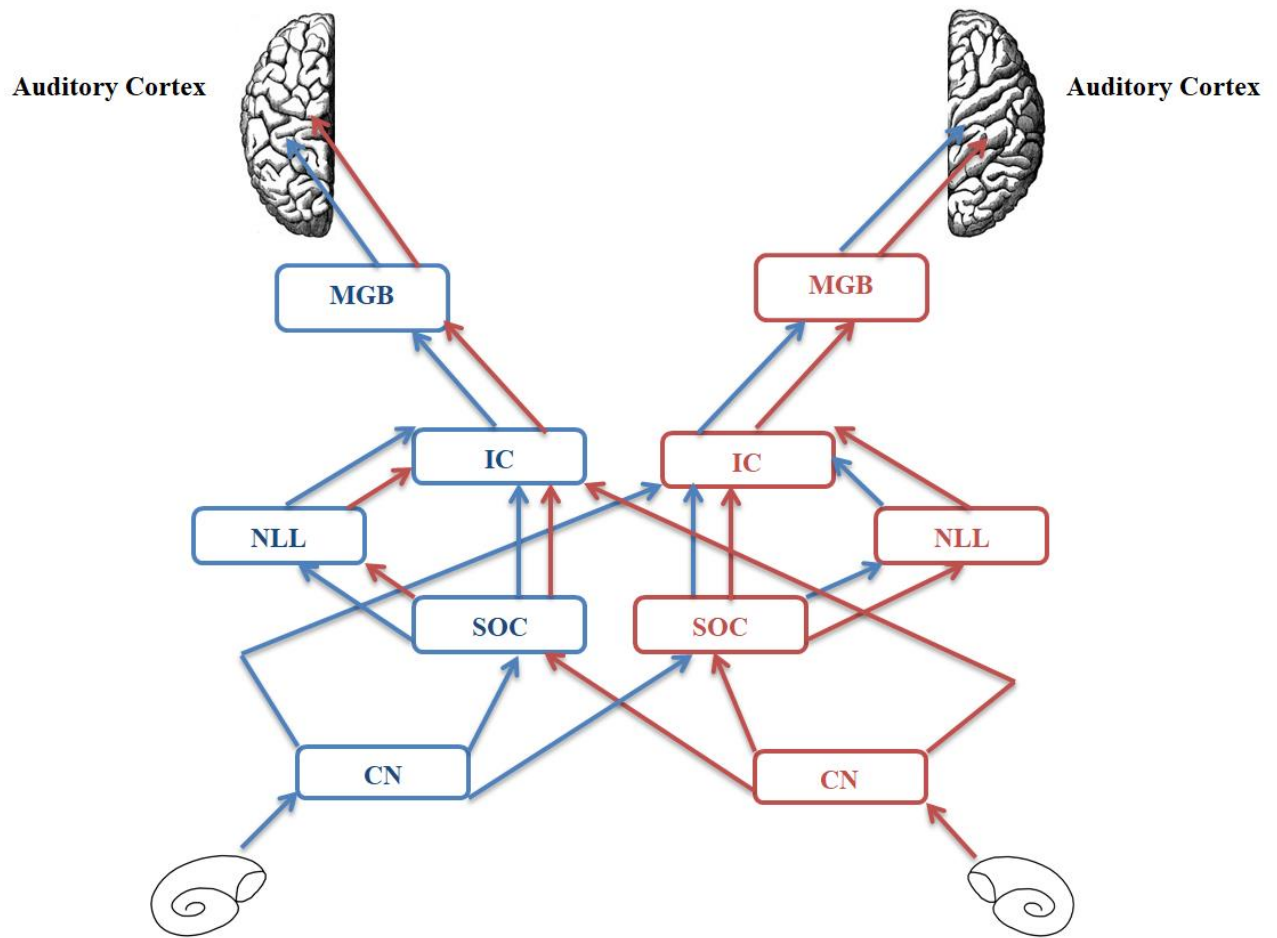


Figure 2. Schematic representation of the left (blue) and right (red) primary ascending connections of the human central auditory pathway, with nuclei initials labelled inside boxes. CN; cochlear nuclei; SOC, superior olivary complex; NLL nuclei of the lateral lemniscus; IC, inferior colliculus; MGB, medial geniculate body. The blue represents left side and the red represents the right. Adapted from Hackett (2009).

The ascending afferent pathway of the subcortical auditory system begins with temporal and frequency specific information being sent from the cochlea through encoding via the displacement of the basilar membrane; thereby initiating action potentials which are then transmitted to the auditory nerve in addition to higher centres of the CAP for further analysis of speech stimulus (Pannese, Grandjean, & Frühholz, 2015). The central auditory pathway's neural network of nuclei begins with the cochlear nucleus, which consists of a variety of neural populations specialised to extract particular aspects of encoded auditory stimulus such as timing, intensity, and temporal features (Romand & Avan, 1997). The signal is then sent to the superior olivary complex (SOC) which receives bilateral projections from the cochlear nuclei. In mammals, the SOC consists of three other subnuclei which are the lateral (LSO), medial (MSO) superior olivary nuclei, and the medial nucleus of the trapezoid body (MNTB). The SOC is the earliest stage of central auditory processing at which inputs from both ears converge and interaural differences in time and intensity are associated with the location of a sound source. This decoding process can be resolved by the circuitry of the LSO and MSO mentioned earlier (Jeffress, 1948). The information is then sent through the lateral lemniscus; a principal fibre tract connecting the SOC and inferior colliculus (Covey & Casseday, 1995). The inferior colliculus (IC) is responsible for the multi-sensory integration of monaural and binaural information for sound localisation processed by lower and higher auditory centres, including an array of connections from the visual and somatosensory centres (Aitkin, 1986). The medial geniculate body (MGB) is the final stage of subcortical processing of ascending auditory information (Jones, 2003). Ascending inputs include but are not limited to all divisions of the IC, thereby transmitting binaural information; however the ipsilateral set of projections is considered to be stronger. Due to the extensive number of projections from several nuclei from the subcortical and cortical auditory fields, the MGB is said to play a role in emotional responses to sound as well as recognition and localisation (Rees, 2009).

At the cortex level, the integrated signal links to memory; thereby allowing for associations of meaning to be developed (Hackett et al., 2007). When the incoming signals work in conjunction with memory for the performance of auditory processing, this allows for the recognition of auditory objects in relation to the environment, and the assessment of behavioural significance of the signal. In addition to the successive auditory nuclei, signal processing occurs both in a serial and parallel manner, thereby resulting in efficient and redundant systems which also pave the way for integration of other processes such as memory, language, and attention (Poremba et al., 2004). One of the most controversially dividing topics between academics when discussing the mechanism of CAP are whether it is more “top-down” (cognitive, learning, and contextual knowledge) driven, or “bottom-up” (the extraction of information along the auditory pathway cascade). This will be explained in greater detail later during section 1.8.

1.3 Maturation of central auditory nervous system (CANS)

The development of the central auditory nervous system (CANS) has been studied and is predicated upon the influence of several factors which consist of both environmental components as well as intrinsic contributions. Essentially, the normal development of the central auditory system, or thalamic-cortical maturation, follows a similar course of the maturation of auditory processing skills (Eggermont & Ponton, 2003). Furthermore, it is not uncommon for superficial layers of the auditory cortex to only reach full maturation until adolescence (Ponton, Eggermont, Kwong, & Don, 2000). However evidence has shown the presence of myelination throughout cortical layers of individuals by six years of age with increased myelination of neural pathways progressing into adolescence (Hallett & Proctor, 1996). Myelin allows for the rapid and precise timing of action potential propagation along neuronal circuits essential for healthy functioning of the auditory system. This increases

transmission strength within and between hemispheres and cortical structures. Furthermore, dendritic branching structures may also continue to mature in complexity up until twelve years of age (Hallett & Proctor, 1996). One method to measure the maturation of the auditory cortex is demonstrated in changes in the individual's cortical auditory evoked potential (CAEP). This phenomenon has shown repeatability in multiple studies by which the P1 component of the CAEP has been deemed the biomarker of CANS maturity through the exhibited relationship of decreased latency and increased amplitude as a function of increasing age (Dorman, Sharma, Gilley, Martin, & Roland, 2007; A. Sharma, Kraus, McGee, & Nicol, 1997; Wunderlich et al., 2006).

In regards to the environmental influences, a study by Kim et al. (2018) suggests a possibility that transient auditory deprivation during critical periods of development can compromise one's ability to discriminate temporal characteristics of sound.

As the central auditory pathway is known to mature through sensory experiences, these environmental inputs have been found to be paramount to brain development during "critical periods" during childhood learning. Developmental psychology defines critical periods as windows of opportunity during which specific experiences have greater effects on the child's development relative to other periods or stages of life (Bailey Jr, 2002). Studies have found the auditory critical periods to be periods in which the auditory cortex undergoes an extensive refinement in order to acquire mature neural organisation – if such growth is delayed it cannot be fully compensated for later in life (Chang & Merzenich, 2003; Kral, 2013).

1.4 Auditory Processing Disorder (APD)

As mentioned above, the mechanisms found along the central auditory pathway play a significant role in the recognition and discrimination of complex sounds through its specialisation of extraction and utilisation of auditory cues (Liberalesso et al., 2012). Thus, there can be a discrepancy between hearing and understanding as it has been found that for some people, the discrimination of complex sounds may be difficult, despite functional and normal peripheral hearing in detecting the presence of sound (Keith, 1981a). Auditory processing disorder cannot be simply be described and dependent on one set of fixed symptoms; but instead is heterogeneous in presentation across those with the disorder. Therefore APD more so describes a variable set of symptoms with the common association to listening difficulties in spite of normal peripheral hearing and normal cognitive capacity (Bamiou, Musiek, & Luxon, 2001).

According to the American Speech-Language-Hearing Association (ASHA, 2005), APD has been found to be associated with the following range of impairments of auditory processing, characterised by below normative performance in either one of more of the following areas: Sound localisation and lateralisation; auditory discrimination; auditory performance with degraded acoustic speech signals and/or competing acoustic signals; auditory pattern recognition; and, time-related (or temporal) aspects of audition. As a result, children with APD can exhibit symptoms of peripheral hearing loss, such as following oral instructions, having difficulty communicating with peers, and thereby affecting their lives academically and socially which may manifest into negative impacts on self-efficacy. Esplin and Wright (2014) report the prevalence of APD in children across the general population of New Zealand to be approximately 5 percent. It should also be noted that APD can also frequently co-occur with other language and learning disorders such as dyslexia, and attention deficit

hyperactivity disorder (ADHD) (Ferguson, Hall, Riley, & Moore, 2011); however proper identification of the contributing factor of APD can often go unnoticed or lead to an inaccurate diagnosis for children by being exclusively diagnosed a single prognosis such as attention deficit disorder or simply poor behaviour without considering the possibility of APD.

1.5 Assessment of APD

Prior to any consideration for APD, a pre-APD assessment must be administered to rule out any potential impairment in the peripheral auditory system. The British Society of Audiology (BSA) has recently released their position statement and practice guidance for APD. They specify that this pre-APD assessment should involve a structured case history, and a well-validated questionnaire in corroboration with previous profession reports.

Furthermore, pure-tone audiometry (250 - 8000 Hz) and immittance testing (including ipsi- and contralateral reflexes) are necessary in the identification of any hearing impairment or medical ear pathology which could be mitigated through medical and/or audiological intervention (British Society of Audiology, 2018). Due to the complexity and heterogeneous aetiology of the CANS by which APD stems from, there is no single test that has been developed and agreed upon as the 'gold standard' for APD assessment (Bamiou et al., 2001). However an APD test commonly comprises of the following categories of behavioural auditory measures (Brown, 1996).

Monaural low-redundancy speech tests: to measure the auditory system's performance in processing speech with reduced intelligibility.

Binaural interaction: to assess binaural processes that underlie the timing, lateralisation, and localisation of acoustic stimuli.

Temporal processing tests: to assess the ability of the auditory system to process time-related cues in an acoustic signal.

Dichotic speech tests: to assess the ability of the auditory system to binaurally integrate and/or separate simultaneously presented speech stimuli.

The category of interest in this particular study falls under monaural low-redundancy speech tests. Although a plethora of tests in this category already exist, such as the synthetic sentence identification (SSI), time compressed sentence test (TCST), and the NU-6 low pass filter test; there still lie pockets of limitations which the UCAST-FW aims to resolve. The BSA concurs by expressing the need to reduce the number of tests while increasing quality with appropriate norms, reliability, and validity. This will be discussed in greater depth in following sections.

1.6 Importance of Speech Audiometry

Speech audiometry is an integral component of any comprehensive audiological test battery.

One useful measurement in particular obtained from speech audiometry is the Speech Recognition Threshold (SRT); the level at which an individual is able to recognize 50% of speech sounds. The SRT in clinical audiology is regarded to be an indication of not just peripheral auditory sensitivity, but also higher order processing and cognitive function. A further justification for spending clinical time to administer such tests is that they provide a cross-check for functional hearing loss (Hornsby & Mueller, 2013). This requires critical

evaluation of testing data to check for consistency between the patient's SRT scores and pure tone thresholds (PTA) results. Furthermore, speech audiometry provides a secondary identifier for unorthodox asymmetries that are not readily apparent in PTA results alone. If diagnosis appears to be pathological or malignant in nature, a referral to the otolaryngologist would be suggested for further testing. However if not, such information may be useful in the decision to fit a unilateral hearing aid fitting. Lastly, speech testing will also provide useful information for the client as a real-world measure of speech intelligibility. This can be used as a counselling tool to monitor progress of performance over time as well as hearing aid candidacy in showing any necessary additional amplification in order to reach a 50% SRT score.

Hornsby and Mueller also discussed the popularity of using monosyllabic word testing in quiet, however their paper lacked the justification for adopted this speech stimulus. Further research of the literature reveals certain factors and commonalities which contribute to valid and reliable speech materials for clinical practice. Firstly, test items should be phonetically varied from one another as to ensure words that rhyme or sound similar to one another are not compartmentalised in the same wordlist. This phenomenon can be attributed to the neighbourhood activation model (NAM) of spoken word recognition. Put forward by NAM (Luce & Pisoni, 1998) has provided a modern theoretical framework for understanding the complex processes involved in recognizing words in relation to active memory. The results from their research support the idea that similar sounding words have a confounding effect on testing speech recognition performance.

Secondly, there should be a degree of familiarity and simplicity to the speech items in an effort to reduce a further co-variable of the individual's lexical knowledge or intelligence that may or may not be contributing to the test results (Calandruccio & Smiljanic, 2012). A study of the development of new speech materials for non-native English speakers revealed that individuals with English as their native language achieved higher scores in comparison to those who did not have a predominantly English-speaking background.

Lastly, when developing a low-redundancy speech test in which the independent variable of degradation of speech is controlled for, it is crucial that all other aspects of the speech sample are homogenous between words. This is to provide equal difficulty across test items in order for valid and reliable results (Ji et al., 2011). Considerations of many factors, including those described above, have been accounted for in the development of the UCAST-FW by which will be discussed in more depth in the following sections.

1.7 Open-set vs. closed-set speech audiometry response formats

The stimuli of a speech test are crucial to its efficacy, but one must not neglect the importance of choosing the appropriate method for individuals to respond when developing the test procedure. Two different response formats are currently utilized in speech tests – open-set and closed-set.

The open-set response format involves the listener repeating or writing the word they heard in the absence of any visual cue, or indicators from multiple choice decisions, even in instances where nonsense syllables are perceived. Scoring is normally carried out by the clinician themselves via a word- or phoneme-based scoring for consonant-vowel-consonant (CVC) monosyllabic test words. In contrast, in the closed-set testing format the participant selects

from a number of options, for instance as a word- or picture-pointing task. Scoring can often be automatically performed by software, which helps to reduce clinician judgement errors. To many clinicians, the closed-set format has remained popular for the simplicity of its administration, which reduces the time spent by the clinician, thereby improving utility of clinical time (Black, 1957). The benefits to using a closed-set response format include reliability of results despite smaller sample sizes (Gelfand, 1998), and that children typically perform better in closed-set tests compared to open-set ones. This poses an advantage for the current study, which involves data collection from children. One disadvantage of the closed-set tests would be the limitation of pre-assigned responses which introduces vulnerabilities of forced responses even when the individual does not hear the word given. When performing studies comparing open-set and closed-set versions of the same test, the closed-set version must be performed after the open-set one to ensure that the open-set one is performed without knowledge of the possible response options.

1.8 Low redundancy, monaural filtered word speech tests

Understanding the processes involved in the human perception and recognition of speech sounds has proven to be an incredibly difficult and complex journey for researchers in the field of CAP. Still to this day, there exists a gaping discrepancy when defining CAP between perspectives of many researchers and clinicians; by which is predicated on one key difference; bottom-up or top-down processing?

To understand these theories, one must first consider the mutual ground of agreement between these schools of thought. Although performance of CAP is dependent on a myriad of factors; there has been agreement on the broad categorisation of intrinsic redundancy and extrinsic redundancy (Teatini, 1970). Intrinsic redundancy focuses on the multiple neural

pathways within the auditory system. This can be seen in the way groups of neurons in the CANS interact to code information when receiving auditory stimulus. Such synergistic information can be redundant especially at the receptor level where each point in the sensory epithelium is represented by a large number of neurons with overlapping receptor fields (Barlow, 1961). Chechik et al. (2006) studied this phenomenon in the ascending auditory pathway through measuring the information content and stimulus-induced redundancy in the neural responses to a variety of natural sounds at three successive stations of the auditory pathway – the inferior colliculus (IC), auditory thalamus (AT), and primary auditory cortex (A1). It found that the IC redundancy was largely related to frequency selectivity. Intrinsic redundancy reduction may be a generic organization principle of neural systems, allowing for easier readout of the identity of complex stimuli in A1 relative to IC. In contrast to this, extrinsic redundancy relates to the acoustic information pertaining to frequency, temporal, and intensity characteristics of speech, lexical experience, word predictability and context (Chermak & Musiek, 1997). The utilisation of both intrinsic and extrinsic redundancies ensures that auditory information is transmitted effectively from the peripheries to the centralities of the auditory system. However the proportion of contribution between extrinsic and intrinsic factors towards CAP is highly debated; this thereby gives rise to the controversial conversation of ‘bottom-up’ versus ‘top-down’ processing. Bottom-up refers to the process of higher-level representations and constructions by the central auditory pathways being predominantly data (sound) dependent. This is also known as the pathway model, by which the evaluation of the CANS is separated into different levels. This suggests testing to do be in a controlled acoustic environment by which auditory processing can be in theory separated from ‘high, non-auditory’ factors such as cognition, language, learning, and memory (McFarland & Cacace, 1995). On the contrary, ‘top-down’ processing emphasizes higher-level constraints, focusing more on concerns around data processing and the

mechanisms involved with the interpretation of auditory speech stimulus. This is the approach taken by the network model by which more pertinence is put on the distributed nature of information processing in the nervous system (Friel-Patti, 1999). In the functional CANS, both intrinsic and extrinsic redundancies can be combined to provide comprehension even in spite of auditory signals being presented in less than optimal conditions. The reality is that the schemes are not mutually exclusive; instead the listening environment is more the determining factor for the contribution of each (Bellis, 2011). Put very simply, auditory processing can be synopsized as what one does with what one hears (Wilson & Arnott, 2013). Low redundancy speech tests (LRSTs) are a common method of evaluating an individual's ability to fill in the missing components of speech signals through controlled manipulation. Degradation of the incoming auditory signal thereby reduces extrinsic redundancies which in turn challenge the individual's intrinsic redundancy to achieve auditory closure in spite of missing gaps in the speech signal. As stated previously, the CANS is responsible for the interpretation of speech signals by which processing is often repeated at different neural sites along the subcortical auditory pathway. However, as APD is the definition for a deficiency in CANS functionality, this thereby reduces the individual's ability to utilize intrinsic redundancies in listening circumstances with low extrinsic redundancy as shown by figure 2. This flow chart essentially simplifies how an individual with functional CAP achieves auditory closure in comparison to an individual with APD. Auditory closure is the ability by which the listener is able to 'fill in the gaps' when parts of the auditory signal are missing or partially unintelligible. Relating this phenomenon pragmatically, one can often find themselves in acoustically unfavourable environments with reverberation or in situations where there is background noise masking the signal of interest otherwise known as low signal to noise ratio; this has much the same effect to artificial manipulation of the speech signal to degrade the extrinsic redundancies that would be otherwise available in a clean speech signal.

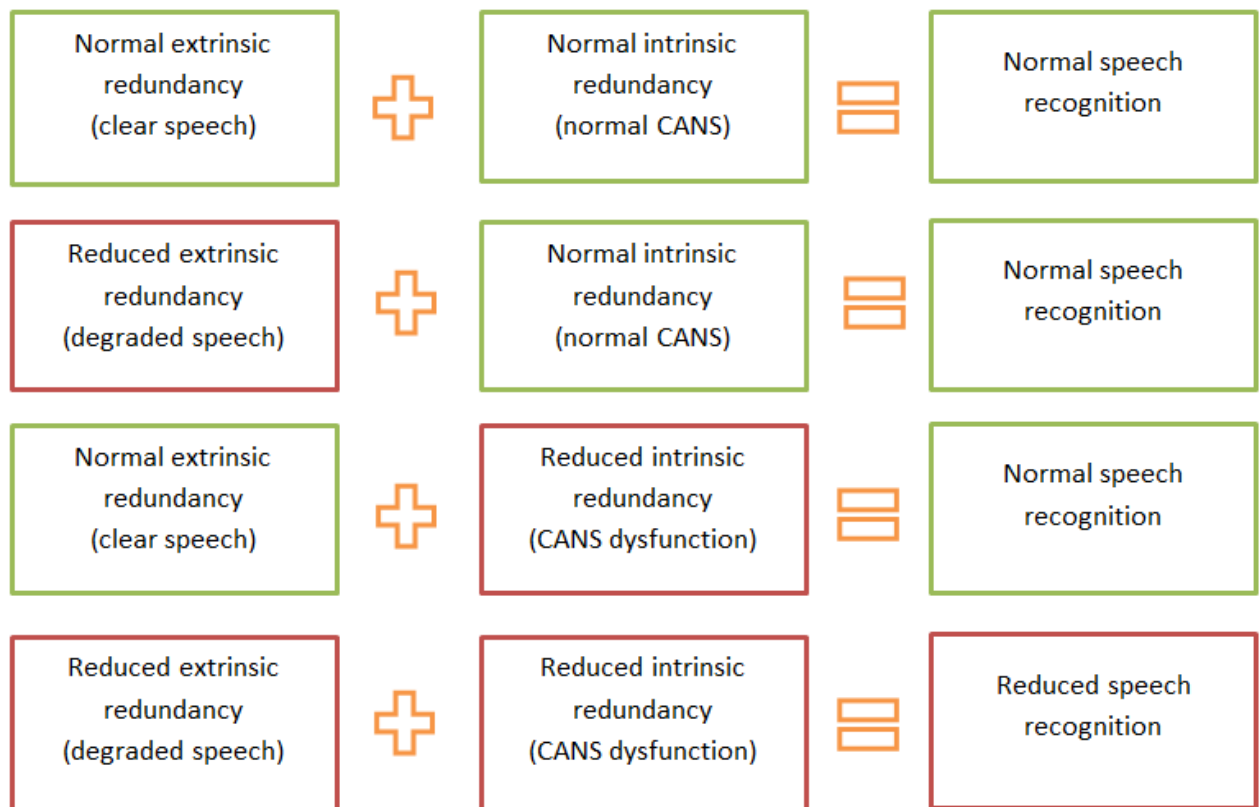


Figure 3. Interaction between intrinsic and extrinsic redundancy. Adapted from Krishnamurti (2007).

Although there exists many different methods of reducing the extrinsic redundancy of a speech signal, the method of interest pertains specifically to the UCAST-FW is the filtered words test. The utilisation of this method in clinical application began as early as the 1950's when Bocca and his colleagues (Bocca, Calero, & Cassinari, 1954) discovered the effect of temporal lobe lesions on the ability to recognise speech stimulus via the peripheral auditory testing. This brought about the hypothesis of reducing the extrinsic redundancies of speech stimuli in order to develop a sufficiently sensitive test to directly challenge the CANS in order to identify possible lesions. With understanding of the approximate frequency range by which speech signals are most prominent which sits from 100 Hz to just above 8000 Hz (Noordhoek, Houtgast, & Festen, 2000), Bocca et al. (1954) was able to apply the test items through a low-pass filter with a cut-off frequency that eliminated spectral content above 500

Hz thereby compromising clarity of consonant sounds – the higher frequencies of which are one of the important extrinsic redundancies that enable the human CANS to recognise complex speech sounds (Rintelmann, 1985). Since then, there have been many different low-redundancy speech tests which employ similar techniques of reducing high frequency content in an effort to challenge the individual's CANS. These tests include but are not limited to the SCAN filtered words subtest, which adopts an open-set response format with a fixed-cut off frequency and 32 dB per octave rejection rate. Within the SCAN, this is subdivided into two different tests referred to as the SCAN-C and SCAN-A test batteries to assess APD in children and in adolescents/adults respectively (Keith, 1994, 2000). Secondly, is the Flowers-Costello Test of Central Auditory Abilities which has a cut-off frequency of 960 Hz (Flowers, Costello, & Small, 1975). Furthermore, Farrer and Keith (1981) applied the Phonetically Balanced Kindergarten speech stimulus presented via audition at a fixed intensity of 50 dB HL while varying the low-pass filter corner from 500 Hz, 700 Hz, to 1000 Hz. Farrer and Keith were able to produce normative mean-scores of 57% to 91% from the ages of 5 years, 8 months to 9 years. Comparing the performance between each corner filter, it was found that using the 1 kHz region provided a significantly clearer separation between performance of children with and without APD, whereas 500 Hz and 700 Hz low-pass filters generated ambiguous and therefore clinically insignificant discrepancies between the normative and APD group. Although the development of low-redundancy monaural speech tests have come a long way since the mid-fifties, there still remain vulnerabilities in test procedures that should be addressed to increase the validity and reliability of this type of test. The evolution of the UCAST-FW – which was developed to attempt to address some of these vulnerabilities – will be discussed in greater detail in subsequent sections.

1.9 Non-adaptive vs. adaptive stimuli

Among the various speech recognition tests available for clinical application, the procedures generally fall into one of two camps: those using non-adaptive fixed-level stimuli, and those using adaptive stimuli. With non-adaptive stimuli, the intensity of each trial is determined before the test commences. An advantage to this type of test is that it can be delivered without a computer (e.g. using a CD player and audiometer). The results of these tests are expressed as percentage correct scores, which are readily understandable by clients and clinicians. However, this also makes them prone to ceiling and floor effects (Keith, 2009).

In New Zealand, the most commonly used speech test by audiologists for testing adults is Boothroyd and Nittouer's meaningful consonant-vowel-consonant (CVC) words (1988). The objective of this test is to provide a reliable estimation of the patient's performance-intensity curve (psychometric function) which is obtained through presenting lists of words monaurally at three different intensities thereby providing three percentages correct scores across varying intensity levels. This monaural three-point psychometric function requires the participant to listen to and repeat back a total of sixty words; one after the other to collect separate ear information across three different wordlists and three different intensities.

Traditionally, these words are presented via a compact disc at a constant, unaltered rate; thus, participants are required to answer to the uncompromising frequency of presentations set by the CD. However as audiological equipment has evolved to becoming integrated on computer based software, audiologists will often take advantage of new user interfaces to control the rate at which words are presented in order to give their patients the best chance of providing a valid response. Scoring CVC words is determined by how many out of possible three phonemes per word are repeated back correctly. This will contribute towards the patient's final percentage correct score which is composed on 10 words per test-list. A minimum of three test-lists are required in order to plot the patient's psychometric curve results. The

validity of test responses is, however, dependent on adequate patient verbal language skills as well as their perception of speech, and on the receptive abilities of the clinician. Patients with intelligible speech production and clear diction will contribute towards reliable and accurate results.

There are some differences between adaptive tests and those that use constant stimuli. The determination of the course that the speech test will take is predicated on gathering data during the test. This involves utilising the preceding presentation of a test item to determine changes to the variable of interest on subsequent test item presentations (Levitt & Rabiner, 1967). Adaptive procedures have several advantages over constant stimuli. As explained by Kaernbach (2001), adaptive procedures yield greater time efficiency as targeting the reception or detection threshold of an individual comes as a result from targeting points on a psychometric function close to that threshold, typically defined as the signal level at which the probability of a correct response is halfway between perfect performance (100%) and chance performance. Further advantages include the avoidance of ceiling and floor effects, which have been found to reduce sensitivity and specificity. For instance, when the cut-off frequency is set too low, even normal listeners struggle to interpret the filtered speech, thereby limiting the ability to distinguish between those with and without APD (Farrer and Keith, 1981).

In an adaptive scenario, the recognition threshold is determined by the ability of the listener. Thus, in contrast to the constant-level methods, the participant will achieve a given percent-correct point on the response curve as oppose to simply having to conform to a specific low-pass filter level. Removing the assumptions for a best-fit frequency improves specificity and accuracy in determining the low-pass filter corner required to obtain a certain proportion

correct on the participant's psychometric curve (O'Beirne et al., 2012). The adaptive procedure also brings about greater efficiency as to promptly eliminate measurements taken too far from threshold, thereby reducing insignificant data points. Greater efficiency during subjective testing often yields more accurate results; especially when testing children as the variables of fatigue, motivation, and attention span are understandably out of the tester's control.

1.10 University of Canterbury Adaptive Speech Test – Filtered Words (UCAST-FW)

The UCAST-FW is an adaptive, monaural, low-redundancy filtered-words speech test (O'Beirne et al., 2012) for the diagnosis of APD in children and adults.

McGaffin (2007) compared the performance on the UCAST-FW in 23 adults (18-55 years, $M = 29.8$), and 32 children (8-11 years, $M = 9.9$ years); all of which had normal CAP. They were required to undertake the UCAST-FW to determine the low-pass corner frequency threshold at which they would score 70.7% correct. Testing was repeated with a resting interval of approximately one week between the two test sessions, enabling test-retest reliability to be assessed. Analysis of the data revealed that there was a significant maturation effect, whereby adults performed significantly better than children participants when controlling for dysfunctional CAP; therefore all participants had normal hearing. However findings also revealed that within the sample population of adults, participants over the age of 35 deteriorated in performance in comparison to adults under the age of 35 ($p=0.0014$). Pertaining to the test-retest reliability, there was a strong correlation between the two sessions despite the one week interval for both ears, both yielding an r value of 0.86 which, as it is ≥ 0.7 , shows acceptable test-retest reliability (according to Ruscetta, Palmer, Durrant, Grayhack, and Ryan (2005)).

Sincock (2008) focused on the clinical applicability of adaptive speech testing using the UCAST platform in speech-in-quiet mode in comparison with conventional speech audiometry with respect to administration time, efficiency, accuracy, and reliability. The adaptive procedures were superior over the conventional “method of constant stimuli” in efficiency, administration time, inter-test consistency, and reliability.

Heidtke (2010) evaluated the efficacy of the UCAST-FW in diagnosing children from the ages of 7 to 13 years. This was done by administering a comprehensive APD test battery across 18 children with suspected APD with an age-matched control group of 10 children with normal CAP. The traditional APD test battery – comprising of the Double Digits test (DDT), the Compressed and Reverberated Words Test (CRWT), the Frequency Pattern test (FPT), and the Random Gap Detection test (RGDT) – revealed that 15 of the 18 suspected children were confirmed to have APD. Results revealed a significant difference between the UCAST-FW low-pass filter limit at which APD and control children scored 62.5% words correct (two-way repeated measures ANOVA, $p < 0.01$). Furthermore, significant correlations were found between the UCAST and three of the four tests used in the APD test battery using a Pearson Correlation coefficient, $p < 0.01$. Heidtke concluded her study by suggesting that the findings provide evidence that an adaptive filtered speech test may improve the sensitivity and specificity of diagnosing APD in children compared to the constant-level counterparts (Rickard et al., 2013).

The assessment of auditory processing in older adults can prove to be difficult due to the natural influence of age on the individual's peripheral sensorineural hearing loss and cognitive declines. Studies by Humes and Roberts (1990) support the notion that peripheral hearing loss increases the difficulty of speech understanding as a result of a reduction of spectral information in the high frequency regions which contain much of the meaning of speech through high-consonant sounds. However, applying a low-pass filter to word tests removes frequency content above 1000-2000 Hz. This in theory should eliminate the confounding variable of peripheral hearing loss when assessing the auditory processing abilities of older adults as performance is not influenced by high frequency acuity. Abu-Hijleh (2011) initiated the investigation of determining the efficacy of the UCAST-FW in diagnosing APD in adults even in the presence of a high frequency peripheral hearing loss. Findings from 19 participants with varying degrees of high frequency sensorineural hearing loss (>25 dB HL at frequencies above 1000 Hz) and 18 participants with normal hearing (≤ 25 dB HL) at 250 Hz through to 4000 Hz bilaterally revealed no significant influences of high frequency peripheral hearing impairments on UCAST-FW performance, indicating it is suitable for use with those clients.

The UCAST-FW has been demonstrated to be both sensitive and reliable in its detection of APD. However, the test stimuli are presented to speakers of New Zealand English using an Australian English recording of test material designed to work in American English. To address these confounding factors, Murray (2012) developed a new four-alternative forced choice test purposed to replace the Northwestern University Children's Preception of Speech (NU-CHIPS) stimuli that the UCAST-FW had been using. Murray developed a new word list consisting of 98 sets of four test items which would be utilised in a closed-set response format for the UCAST-FW. The study described the new word list's clinical applicability to

have potential through further exploration; however the current version of the UCAST-FW continues to use the NU-CHIPS speech stimuli.

Most recent to the time of this dissertation, Gibbins (2017) made further improvements to the validity and reliability of the UCAST-FW by being the first to recognise the heterogeneity between the test items of the word lists being used in the test. The large variance in the spectral content produced inequitable filtering between test items meaning that words with greater high frequency content are more difficult to discriminate compared to lower frequency words even when both words have the same low-pass filter corner frequency. These adjustments were performed through the utilisation of a novel method of normalisation that adjusted the level of low-pass filtering for each test item so that its performance was equivalent to the mean performance for the entire word list in such a way that considers the psychometric slope of each test word rather than just the midpoint of the function. Results from testing 61 English speaking adult listeners with normal hearing revealed that this adjustment process was successful in achieving a more homogenous word list for both open and closed set response formats, as evidenced by a cleaner, more normally-distributed cluster of psychometric functions.

Though the UCAST-FW has evolved over the years, it cannot be implemented successfully in clinical settings without first quantifying in a larger sample the significant maturational effect seen in the initial UCAST-FW study (O'Beirne et al., 2012), where the performance of normal listening children participants improved with age. This would result in a set of age-reference norms against which an individual child's performance could be compared.

1.11 Purpose for collection of normative data

Although the human peripheral auditory system becomes fully developed by birth, the development of the CANS as mentioned earlier in section 1.3, takes time to fully develop. Myelination continues for several years in the higher auditory pathways, which aren't simply dependant on physiological and neurological factors, but also require contributions from experience through communication and lexical and phonetical recognition. This phenomenon has been investigated through multiple studies, however one in particular conducted by Schochat and Musiek (2006) demonstrated increased performance with increased age on both spectral and temporal resolution from the age of 7 to 12 years old. These were bracketed into the age groups of 7 to 8-, 9 to 10-, and 11 to 12 year-old groups shown below in figure 4.

Mean data for each age group for the pitch and duration pattern						
Age groups	Díchotic digits		Pitch pattern		Duration pattern	
	RE (%)	LE (%)	RE (%)	LE (%)	RE (%)	LE (%)
7-8	95.27	94.38	47.49	48.97	43.02	44.25
9-10	96.01	94.96	63.30	62.34	57.29	56.32
11-12	98.11	96.48	69.47	69.72	66.25	64.80
13-14	97.50	96.83	75.73	75.63	72.89	72.40
15-16	99.06	97.69	76.67	76.41	73.15	72.74

Figure 4. Mean data for each age group for the pitch and duration pattern, acquired from (Schochat & Musiek, 2006)

The results from this study show that the natural course of CANS maturation found in one hundred and fifty children with normal peripheral hearing has an impact on the performance of common test batteries which assess CAP function. More importantly, this maturation dilemma is consistent with studies on the UCAST-FW as discussed O'Beirne et al. (2012). Comparisons between 8- and 11- year old children with no known history of listening difficulties revealed a trending reduction in the required low-pass filter corner frequency in order to achieve their 70.7% threshold with increasing age.

This improvement in performance was also similarly reported by Willeford (1981b) when testing children from the ages of 6 to 10 years using his fixed 500 Hz low-pass filtered speech test. However this correlation between age and performance does not follow a linear regression of variance; but instead the variability of performance decreases with age. This essentially indicates that the older the child is, the more stable and homogenous their CANS development becomes between one another in comparison to younger children where the progress of their neural development may be quite varied from one child to the other.

The significant implications that maturation can have on APD testing raises concerns on the internal validity of the sample population when conducting research and development on APD tests. Internal validity refers to how thoroughly an experiment is undertaken with efforts taken to avoid the vulnerabilities of confounding factors by which more than one possible independent variable may act simultaneously (Salkind, 2010). Increased internal validity is dependent on the experimental design's vigilance against confounding variables. This will in turn improve the researcher's confidence of results when making associations and attributions between variables. This is especially important when researchers are unclear on whether the participant's poor performance was attributed solely by their CAP capabilities, or if their age should be taken into consideration as a factor seen across the normative population.

Normative data provides characterization of what is usual in defining a population at a specific point or period in time (O'Connor, 1990). Collecting such data can be useful for establishing illness nosologies suitable for primary care research, describing the natural history of clinical conditions in a given community, but more relevant to this study; it can help to develop standards of care for primary physicians. The literature however does caution that collecting normative data requires meticulous exclusion of participants with any

indication of peripheral hearing loss or history of listening difficulty in an effort to avoid contamination of a sample group that claims to be representative of the normal population (Cameron & Dillon, 2007). Normative data would need to be collected from a sample size that is representative of the population of children in New Zealand in order to analyse the distribution of typical performance across children with no history of peripheral hearing or listening difficulties from the age of six to twelve years. The intention behind the analysis is to produce age-related correction factors that would be applied to ensure that children of difference ages are not measured by the same standard. This is because their age may contribute an unfair advantage for older children or a disadvantage for younger children. Correcting for the confounding variable of maturation would improve internal validity and overall accuracy of diagnosis and clinical efficacy of the UCAST-FW; thereby bringing it one step closer to clinical application in New Zealand.

1.12 Statement of the Problem

Today, there exists a plethora of tests in clinical application, all of which have been developed for the purpose of diagnosing auditory processing disorder. Despite the great progress achieved since the disorder was first discovered by Helmer Myklebust in the mid 1950's (Myklebust, 1954), there is much room for improvement pertaining to efficiency and accuracy which is especially pertinent for diagnosing APD in children. The UCAST-FW has adaptive stimulus adjustment to mitigate floor-ceiling effects and utilises a novel method of normalisation which should improve the accuracy and efficiency of the test.

The New Zealand Ministries of Health and Education Expert Reference Group recognised the UCAST as being suitable for use by audiologists in New Zealand, with the authors noting that it had acceptable test-retest reliability, established validity, demonstrated sensitivity and specificity, clinical acceptability, and published studies (APD Reference Group, 2017).

Another step towards improving the clinical applicability of the UCAST-FW would be to quantify in a larger sample the significant maturational effect seen in the initial UCAST-FW study (O’Beirne et al., 2012), where the performance of normal listening children participants improved with age.

The present study aims to quantify a significant maturational effect found between younger and older children participants when presented with the UCAST-FW (O’Beirne et al., 2012). Therefore, normative data will be required to define the normal range of UCAST-FW results expected from children with attributes typical and representative of the general population in New Zealand. However, in the time frame available it was not possible to recruit an adequate number of participants to enable the data to be truly normative. Therefore this study will focus on the primary hypothesis as follows:

This primary hypothesis will be predicated on the outcome of a regression analysis which serves to organise the proportional impact of potential predictor variables against the variable of interest (Becker and Chambers, 1984).

Chapter Two:

Methods

2.1 Recruitment

Statistically, the number of participants required for recruitment was predicated on a power analysis (Bausell & Li, 2002) that indicated eleven participants per age group from six to twelve years old would yield an 80% chance of detecting an effect size of 0.64 between the mean scores of subsequent age groups, for the UCAST-FW, but also for the UCAMST-P, which is being tested alongside the UCAST-FW as part of a related study (Lay, 2019). This effect size was calculated from another study which also sought to gather normative data of the paediatric population for a speech recognition based test (Neumann et al., 2012). This, therefore, meant that the target sample size for this study would be seventy-seven. It was decided to have eleven participants per age group even in older children, despite past studies showing decreasing variability of performance with age, which would suggest that fewer participants would be needed in the older age group.

Furthermore, this number was chosen to provide an accurate estimation of word recognition performance between different wordlists across a variety of age brackets, as required for calculation of the psychometric function based on previous experiments involving the UCAST-FW. Logistically, time and funding constraints limited the recruitment prospects and resulted in a significantly lower sample size compared to what is required for normative data collection. The specified inclusion criteria included the following requirements; participant age should be between six to twelve years of age and they must have normal hearing down to screening level across the speech dominant frequencies of 500, 1000, 2000, and 4000 Hz at screening levels of 30, 20, 20, and 20 dB HL respectively (Ministry of Health, 2014).

Furthermore, the participants were to have no current middle ear pathology such as ear infections or past surgeries at the time of testing as well as no history of neurological disease or impairment. However, if a child were to exhibit traits that contradicted one or several of these inclusion factors, testing would still be carried out, but with post-hoc coding to ensure that participants who did not meet inclusion criteria were kept separate from the 'normative' sample. Participants were recruited from three sources. The first was the Team Tamariki database; an initiative founded by the University of Canterbury and New Zealand Institute of Language, Brain, and Behaviour (NBILBB) with the purpose of developing a database of families whom are willing to be contacted for research projects given that they meet the required criteria for the study. This involved communication with NZILBB manager Megan McAuliffe to assist with the distribution of information sheets and consent forms. From here, interest of involvement would be communicated through the manager forwarding the completed parent/guardian consent form to the researchers. Subsequently, direct communication between the parent/guardian and researchers would lead to the scheduling of appropriate testing session times as well as follow up information provided by the parent/guardian regarding the child's school and teacher's name in order to complete the teacher questionnaire. All of the participants' parents/caregivers were provided with comprehensive insight into the purpose of the study, expectations between each party in the event of agreement to participate, and clarification that all participant information will remain in confidence. The second source of participants was four primary schools in the Christchurch region, with socio-economic status (SES) being a deciding factor. This was to ensure the acquisition of the test sample wasn't skewed by an unfairly weighted socio-economic dominance across household incomes ranging from \$50,000 - \$100,000 per year (Christchurch City Council, 2013). Although this study does not aim to gather a sample size sufficient for normative analysis, it is still important to consider the implications of SES with

respect to its comorbidity to the literacy abilities of children, as exhibited in a study conducted by Carroll, Maughan, Goodman, and Meltzer (2005). Furthermore, research on the conducted on the prevalence of APD in school aged children in the Mid-Atlantic region found that prevalence of APD in children who attended private schooling was more than two times higher than children who attended public schools (Nagao et al., 2016).

Finally, a third facet of recruitment was employed towards the end of testing at primary schools due to a shortage in participants from the 11-12 year old age group. This was evidently due to two out of the four schools limited to years 1-6, thus a higher proportion of the sample size acquired from school were from the ages of 6-10 years old. In order to mitigate this issue, 11-12 year old students from Dorayme Music Tuition Studio Ltd were recognised first through the principal – Christy Phang Mooi Yau. This was followed up by the researchers directly contacting the Parents/guardians of children recruited.

All participants in this study received a free hearing screening as well as being offered a \$10 Motor Trade Association (MTA) voucher as an honorarium of appreciation for their willingness and time for participation with an additional audiological presentation for the teachers of the participating schools to contribute to professional development hours. Ethical approval for this study was obtained from the University of Canterbury Human Ethics Committee, reference 2018/04/ERHEC-LR, as displayed in Appendix A.

2.2 Participants

This study gathers data from child participants, all of whom shared the common typical traits of normal auditory, behavioural, cognitive, and neurological development, as stated previously in the inclusion criteria of 2.1. There were 143 English-speaking child participants in this study (79 males and 54 females), with an age range from 5 years 11 months to 13 years 0 months. Despite the stringent inclusion criteria, exceptions were

made for 41 participants who, despite not meeting all criteria, were still tested, but who were tagged for post-hoc analysis to prevent any significant covariates outside of normality to enter the dataset . Figure 4 below provides a summary of the additional conditions and services that the participants had. These disorders included neurological conditions such as attention deficit disorder/ADHD, autism spectrum disorder, and auditory processing disorder. Language factors such as delayed speech-language as well as learning English after 5 years of age were also included. Although some participants may have ticked one or several of these conditions, they were still eligible for the study as a regression analysis will be conducted in order to determine whether the presence of any of these conditions would have a significant impact on UCAST-FW scores.

6. Please ☒ any of the following conditions or services experienced by your child
- a. ☐ Attention deficit disorder/ADHD
 - b. ☐ Auditory processing disorder (C-APD)
 - c. ☐ Autism/Asperger syndrome
 - d. ☐ Chronic middle ear infections or surgery
 - e. ☐ Developmental delay
 - f. ☐ Dyslexia (or language learning disability ☐)
 - g. ☐ History of speech-language delay or therapy
 - h. ☐ Jaundice as newborn: (a) Mild ☐ (b) Moderate ☐ (c) Severe ☐
 - i. ☐ Learning disability
 - j. ☐ Learning English as a 2nd language after age 5
 - k. ☐ Permanent hearing loss:
 - (a) Mild ☐ (b) Moderate ☐ (c) Severe ☐ (d) Unilateral ☐
 - (e) Hearing aid ☐ (Left/Right/Both) (f) Cochlear implant ☐ (Left/Right/Both)
 - l. ☐ Special education
 - m. ☐ NONE OF THESE

Figure 5. Parent questionnaire adapted from Dr. Brian O’Hara’s APDQ 2017 version I: for parents and teachers of children aged 7 to 17 years old

As well as the parents receiving a questionnaire, the participant’s school teacher was also given a short questionnaire to fill out. The questionnaire begins with a short selection of yes/no questions to find out if the participant’s reading, writing, language,

and behaviour was at the expected level for their age. As APD can sometimes present itself in delayed literacy skills and has comorbidity to behavioural disorders, it was important to attain information of this relevance. Furthermore, the Teacher Evaluation of Auditory Performance (TEAP) (Purdy, Kelly, & Davies, 2002; M. Sharma & Purdy, 2013) was also employed as part of the teacher questionnaire. The TEAP as shown below is a one page questionnaire containing a total of 10 questions, divided into two sections; A and B. The first four questions (section A) are scale questions from +1 (less difficulty) to -5 (cannot function at all). The second section (section B) contains yes/no questions. For this section a 'yes' response was coded as 0 and a 'no' response was coded as a 1.

This meant a positive score for both sections A and B of the TEAP indicated less difficulty. Multiple authors have advocated the TEAP's efficacy for teachers as it has been shown that children with suspected auditory processing difficulties score lower on the TEAP compared to typically developing children (Barry, Tomlin, Moore, & Dillon, 2015; Purdy et al., 2002). Furthermore, a recent dissertation by Keat (2016) showed six significant relationships between one or more TEAP factors and auditory processing test data. Therefore, children with a higher score for a test variable also scored higher on the TEAP, as reported by their teacher, and were perceived to have more difficulties in areas related to listening.

3. Teacher Evaluation of Auditory Performance (TEAP)

Please rate this child's behaviour compared to other children of similar age and background.

SECTION A. RESPONSE CHOICES

Less difficulty.....	+1
Same amount of difficulty	0
Slightly more difficulty	-1
More difficulty	-2
Considerably more difficulty	-3
Significantly more difficulty	-4
Cannot function at all.....	-5

If listening in a room where there is background noise such as others talking, children playing etc., this child has difficulty hearing and understanding..... +1 0 -1 -2 -3 -4 -5

If listening in a quiet room (others may be present, but are being quiet), this child has difficulty hearing and understanding..... +1 0 -1 -2 -3 -4 -5

When listening in ideal conditions (quiet room, no distractions, face-to-face, good eye contact), this child has difficulty hearing and understanding..... +1 0 -1 -2 -3 -4 -5

This child has difficulty following multistage oral instructions +1 0 -1 -2 -3 -4 -5

SECTION B. Please circle YES or NO

This child appears to have trouble picking up new spoken information and may require several repetitions in order to understand the material.....YES/NO

This child frequently requires visual cues to help understand the curriculum, in addition to auditory information.YES/NO

This child has difficulty recalling auditory information, compared to other children.....YES/NO

This child displays difficulty formulating or generating expressive language, and/or displays inappropriate use of languageYES/NO

If YES, please explain:

The child displays language problems (evidenced in the usage of inappropriate "wh" questions, pronouns, word order, possessiveness, verb tenses)YES/NO
If YES, please explain:

This child displays problems with articulation (phonology) consisting of substitutions, distortions, or omissions of sound in words (especially when producing words that sound similar)YES/NO
If YES, please explain:

Figure 6. Teacher Evaluation of Auditory Performance (TEAP) Questionnaire (Purdy et al., 2002; M. Sharma & Purdy, 2013)

2.3 Equipment

In order to carry out pure-tone audiometry for the audiological assessment and tympanometry immittance testing of the middle ear function, two different configurations were used and was dependent on whether testing was undertaken at the University of Canterbury or offsite at the child's school. For the participants that were tested at the University of Canterbury Speech and Hearing Clinic (predominantly coming from the Team Tamariki pool of families), a GSI-61 (Granson-Stadler Inc.)

audiometer was used in conjunction with the TDH-50P supra-aural headphones. These audiometric tests were all performed in compliance with the university's audiology protocols and guidelines through the appropriate testing environments of the sound-treated audiological booths at the University of Canterbury the Speech and Hearing Clinic. Tympanometry was conducted using the Clarinet Inventis or the GRASON STADLER Tymptstar Tympanometer. As for off-site testing in schools, a screening audiometer and screening tympanometer was used for the same audiological assessments. However, testing reliability may have been compromised due to the limitations of using rooms without sound-treated properties for the testing of children. This concern derives from research that shows noise levels in school classrooms measured in different scenarios. Environments in which children were 'quiet' measured in at 55 dB(A), whilst noise levels around 77 dB(A) were recorded when the pupils were working (Dodd, Wilson, Valentine, Halstead, & McGunnigle, 2001). Although the specific testing site within the schools was not yet allocated, there were still concerns of noise interference from adjacent or nearby classrooms during testing. The UCAST software platform developed by O'Beirne, T. (2007-2018) [UCAST-FW]. Canterbury: Christchurch. was installed on a personal computer (PC) from the University of Canterbury. This software delivered the UCAST-FW and UCAMST-P tests. The PC had a dual monitor set-up, with the second screen being a touchscreen. The touchscreen was used for the picture pointing exercise in the closed test portion of testing.

2.4 Stimuli

The speech recognition stimuli used for this iteration of the UCAST-FW came from a recording from the Northwestern University Children's Perception of Speech (NUCHIPS) test extracted from the "Speech Recognition Materials" CD 1 (National Acoustics Laboratories, Chatswood, NSW, Australia). Once fed through the filtering algorithms of the UCAST, all stimuli were subject to a degree of low-pass filtering based on the individual performance of the participant in the preceding trials. Elliott and Katz (1979) reports the NUCHIPS test's reliability down to ages as low as 2.6 years of age given receptive vocabulary is typical. In this study, however, the inclusion criteria restricted eligibility to at least 6 years of age. Speech stimuli were delivered binaurally through Sennheiser HD280 headphones via a Creative Labs SB1095 external sound card to ensure impedance (and therefore output levels) stayed constant across testing, regardless of the computer used for the testing.

As mentioned above, all words in the NUCHIPS recording were subject to low-pass filtering performed using a 10th order Butterworth filter, intended to pass frequencies below a specified rejection threshold at a rate of 60 dB/octave. The output level of the stimuli was maintained at a constant level through a headphone-specific equalization process with an LEQ normalization calculation.

To ensure audibility was sufficient enough not to affect word recognition or discrimination, the target output level was set to 65 dBA. The sound treated booths facilitated an ambient noise floor of less than 40 dBA during testing procedure whereas the designated class rooms in the schools were not sound treated thereby posing vulnerabilities of ambient noise levels effecting UCAST-FW performance. The Ministry of Health's national vision hearing screening protocol (Ministry of Health, 2014) states that hearing screenings must be taken place in environments with less than 40 dBA. Unfortunately many of the test sessions at the primary schools would not have complied with this acoustic requirement.

2.5.1 Procedure

The aim was to complete testing in no more than 45 minutes for the purposes of i) improving time efficiency, thereby enabling the allocation of more appointments within a day's testing; and ii) to reduce fatigue effects, which may compromise the reliability of results obtained from children participants.

2.5.2 Audiometry

All participants underwent visual inspection of the external auditory canal and ear drum via otoscopy, and were screened bilaterally using air conduction pure tone audiometry from the frequencies of 500Hz to 4000Hz to rule out any peripheral hearing loss. In the event that a participant did not respond to the pure tones within normal limits, thresholds were measured in 5 dB steps using an adapted version of the modified Hughson-Westlake procedure. The adapted procedure reduced testing time by screening the participant's hearing in accordance to the Ministry of Health (2014) National Vision and Hearing Screening Protocols as oppose to threshold seeking.

According to Stimuli were generated by a calibrated Grason-Stadler GSI 61 and presented to each ear TDH-50P super-aural headphones for standard pure-tone audiometry.

2.5.3 Tympanometry

In order to assess middle ear function, immittance audiometry following the University of Canterbury's protocol for tympanometry was undertaken using the Clarinet Inventis. Tympanometer settings were set at a sweep rate of 200 daPa/s³ with a probe tone of 226 Hz. The protocols suggest testing pressures to +/- 200 daPa to be sufficient, however in instances whereby differentiation of a Type C and Type B tympanogram was difficult, the pressure sweep was extended to -400 daPa .

2.5.4 Dissertational Alliance

The participants and data for this dissertation were gathered in alliance with fellow Masters of Audiology student Marie Lay for her thesis "Development of the University of Canterbury Paediatric Auditory-Visual Matrix Sentence Test (UCAMST-P): Sentence Equivalence and Normative Data". Therefore, participants also underwent testing for the UCAMST-P in addition with the UCAST-FW. To compensate for fatigue effects, the test order was randomly counterbalanced among all participants, resulting in a dataset that is not vulnerable to biased performance in favour of one test over the other (Shuttleworth, 2009). Testing was carried out by both Marie and I irrespective of which test was being presented in order to optimize testing availability should we be required to test two separate participants simultaneously.

2.5.5 UCAST-FW Closed Set

The closed set version of the UCAST-FW; a 4-AFC picture-pointing task was administered via a touch screen monitor. Before testing commenced, instructions to the participant (as shown in appendix B) were delivered verbally followed a brief training session to ensure all participants knew the test words corresponding to the pictures. This was carried out by asking the participant to verbally repeat what they thought each picture was trying to convey (e.g. whether it was a dog or a fish). All test items, including the distractor items, were run through and corrections for words such as “boat” instead of “ship” helped to ensure the participants were informed what they should be hearing. This was followed up with a set of 15 practice runs, with the easiest practice low-pass filter frequency at 1000 Hz progressively decreasing to 400 Hz. To illustrate the user-interface of the UCAST-FW, Figure 7 shows an example of the word “shoe” being presented acoustically with a selection of 4 alternative pictures to choose from.

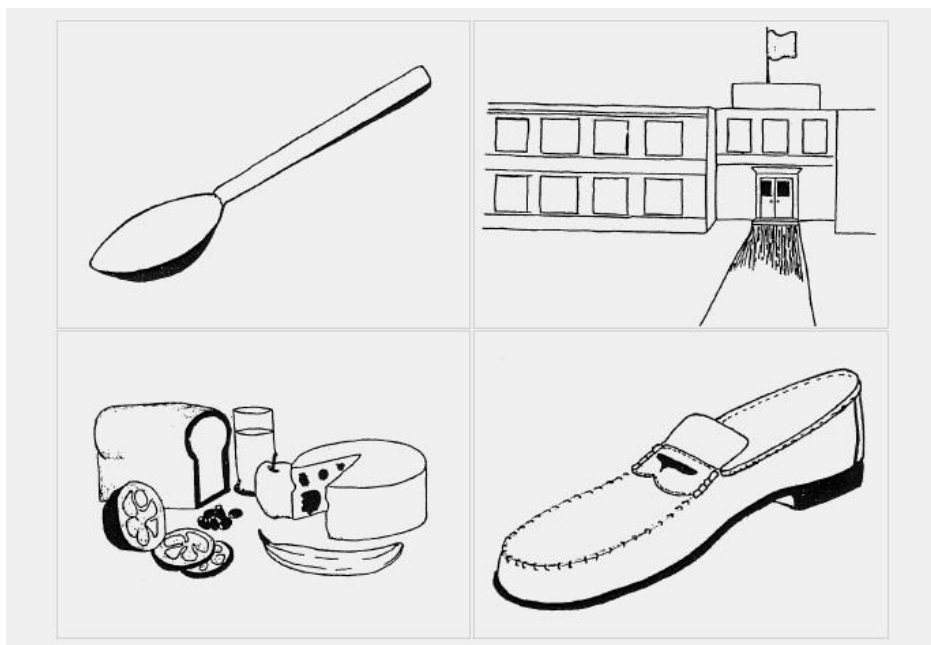


Figure 7: An example display of four-alternative picture choices for the acoustically presented test word “shoe”. Bottom left: food, top left: spoon, top right: school, bottom right: shoe.

Furthermore, the presentation order of the 50 words was randomised along with randomization of the location of the four pictures. Scoring was binary with zero recorded for an incorrect response, or a one, as the correct response. Given there are four alternatives, the chance score was on mean 25%. The test runs until 20 reversals have been achieved, with the threshold being calculated as the mean of the last 15 reversals. Data is saved to a text file. Two monaural runs of the test procedure on both the right and left ear are also then conducted to assess discrepancies between ear performances on the UCAST-FW. While the right and left ear order were randomised, the intent was to always start with the binaural run. This procedure was later found to be compromised with a small number of participants in the beginning of the testing phase as communication of testing sequence needed to be explained clearer.

2.5.6 UCAMST-P

As mentioned above, data was also collected with the aim of evaluating developing a paediatric version of the University of Canterbury Auditory-Visual Matrix Sentence Test – an audiological speech test that measures how well people understand sentences with and without the benefit of seeing the person who is talking. Due to the open-set nature of the test, the response from the participant was verbal, therefore a training session was administered prior to the test to ensure that all 18 words could be understood and pronounced sufficiently for the researcher to reliably mark their score. Two unilateral runs of the test were conducted on each ear to analyse discrepancies between ear performance.

2.6 Statistical Analysis

Using Microsoft Excel, a spreadsheet was developed to store and compare all the information gathered from the parent questionnaire, teacher questionnaire, and the peripheral hearing results from the testing session. This data was used to investigate covariances that may have had an impact on UCAST-FW performance. These data were exported into IBM SPSS Statistics Data Editor for statistical analysis.

Chapter Three:

Results

3.1 Missing Data

Between the acquisitions of obtaining 143 participants for this dissertation, a considerable amount of time was allocated towards administration and correspondence between the participants' parents to receive consent forms and questionnaires. Due to nature of this one year research project requiring the involvement and participation of hundreds of people, made up of child research participants, teachers, and parents; consequently there was some missing data by which could not be obtained due to a variety of circumstances. Those missing data is quantified in Table 1.

Table 1.

Table displaying scale and nominal co-variables presented with their respective missing data points

Potential Predictor Variable	Valid	Missing
Gender	133	10
Ethnicity	117	26
Other Ethnicity	49	94
Is English First Language	118	25
If Not, Age Acquired	5	138
Additional Conditions/Services	118	25
Other Conditions/Services	143	0
RWLB at present	102	41
RWLB in the past	103	40
RWLB present vs past	105	38
Pure Tone Audiometry	143	0
Tympanometry Right Ear	143	0
Tympanometry Left Ear	143	0
Otoscopy Right Ear	143	0
Otoscopy Left Ear	143	0

Over the data collection carried across 37 days, a total of 143 participants were screened and tested using the UCAST-FW. The mean age (N=119) was found to be 9.52 years (SD = 1.90) whilst the mode age was 9.50 years. The participants covered an age range from 5 years 11 months to 13 years 0 months, which ensured that the spread of the data was sufficient to measure the maturational effect of the CANS.

Among the participants, gender was split 54 to 79 between females and males participants respectively (N=143).

Regarding the ethnic diversity of the sample (N=117), 104 participants reported that they were European while 2 and 11 participants were of Māori and Chinese descent respectively.

3.2 Trimming Outliers

Upon visual inspection of a box plot (figure 8) displaying the mean LPF threshold of three different conditions for the UCAST-FW consisting of binaural, monaural right ear, and monaural left ear, various significant outliers were found. Subsequently, a total of 22 participants were removed from the dataset as to ensure normally distributed data.

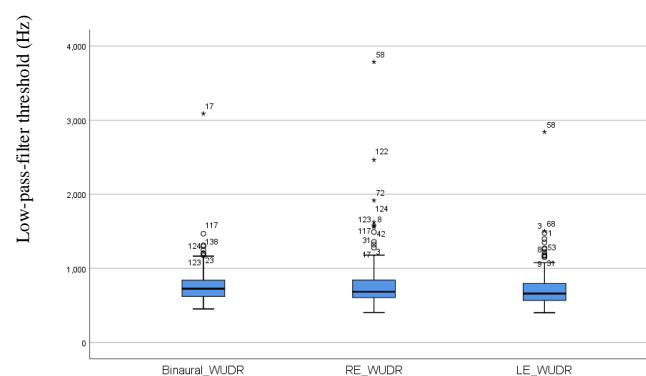


Figure 8: Box plot displaying the LPF threshold of three different conditions for the UCAST-FW

As a result of trimming the outliers, the remaining participants' demographic information from parent and teacher feedback is shown in the tables below.

Quantitative Results

Table 2.
Quantitative details of data set pertaining to gender

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Female	47	38.8	42.0	42.0
	Male	65	53.7	58.0	100.0
	Total	112	92.6	100.0	
Missing		9	7.4		
Total		121	100.0		

Table 3.
Quantitative details of data set pertaining to Ethnicity

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	European	90	74.4	86.5	86.5
	Māori	2	1.7	1.9	88.5
	Chinese	12	9.9	11.5	100.0
	Total	104	86.0	100.0	
Missing		17	14.0		
Total		121	100.0		

Based on the parent questionnaire, participant ethnicity was selected from main ethnic groups derived from options provided by Statistics New Zealand (Zealand, 2012). Missing data (n=17) was due to omission by the parent.

Table 4.*Quantitative details of data set pertaining to “Other” ethnicity*

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Indian	2	1.7	5.7	5.7
	Japanese	2	1.7	5.7	11.4
	Korean	1	.8	2.9	14.3
	Chinese/Italian	2	1.7	5.7	20.0
	Māori/Scandinavian	1	.8	2.9	22.9
	South African	1	.8	2.9	25.7
	Persian	1	.8	2.9	28.6
	Dutch/Mauritian	1	.8	2.9	31.4
	Cook Island Māori	1	.8	2.9	34.3
	Māori	11	9.1	31.4	65.7
	Chinese	1	.8	2.9	68.6
	Thai	1	.8	2.9	71.4
	Filipino	1	.8	2.9	74.3
	Missing	9	7.4	25.7	100.0
	Total	35	28.9	100.0	
Missing		86	71.1		
Total		121	100.0		

Of the 121 participants, 35 parents provided additional information to clarify the precise ethnic contributions of their child.

Table 5.*Quantitative details of data set pertaining to responses for “Is English First Language?”*

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	99	81.8	95.2	95.2
	No	5	4.1	4.8	100.0
	Total	104	86.0	100.0	
Missing		17	14.0		
Total		121	100.0		

“Is English First Language” seeks to separate participants who acquired English as their first language and those who did not; to which a follow up question will be asked as shown below.

Table 6.*Quantitative details of data set pertaining to responses for “If Not, Age Acquired”*

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	5 Years Old	4	3.3	80.0	80.0
	6 Years Old	1	.8	20.0	100.0
	Total	5	4.1	100.0	
Missing		116	95.9		
Total		121	100.0		

As mentioned above, the parents’ participants whose first language was not English were then asked to provide the age at which their child first acquired English. Of the 5 participants who did not learn English as their first language, the age of acquisition ranged from 5 to 6 years old.

Table 7.*Quantitative details of data set pertaining to Additional Conditions/Services*

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	None of These	63	52.1	60.6	60.6
	Attention deficit disorder/ADHD	1	.8	1.0	61.5
	Auditory processing disorder (C-APD)	1	.8	1.0	62.5
	Autism/Asperger syndrome	1	.8	1.0	63.5
	Chronic middle ear infections or surgery	9	7.4	8.7	72.1
	Dyslexia (or language learning disability)	2	1.7	1.9	74.0
	History of speech-language delay or therapy	8	6.6	7.7	81.7
	Jaudice as newborn - MILD	13	10.7	12.5	94.2
	Jaudice as newborn - MODERATE	3	2.5	2.9	97.1
	Jaudice as newborn - SEVERE	1	.8	1.0	98.1
	Learning English as a 2nd language after age 5	2	1.7	1.9	100.0
	Total	104	86.0	100.0	
Missing		17	14.0		
Total		121	100.0		

Table 8.

Quantitative details of data set pertaining to participant's reading, writing, language, and behaviour against national standard at present

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Pass	66	54.5	77.6	77.6
	Fail	19	15.7	22.4	100.0
	Total	85	70.2	100.0	
Missing		36	29.8		
Total		121	100.0		

Additional services and conditions adapted from Dr. Brian O'Hara's APDQ 2017 version I

Information provided from the teacher questionnaires asking yes/no questions to find out if the participant's reading, writing, language, and behaviour was at the expected level for their age. Pass indicates that the participant (student) meets all four disciplines against the national standard at present whereas fail indicates that one or more of these areas were not at the expected level for their age.

Table 9.

Quantitative details of data set pertaining to participant's reading, writing, language, and behaviour against national standard in the past

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Pass	59	48.8	69.4	69.4
	Fail	26	21.5	30.6	100.0
	Total	85	70.2	100.0	
Missing		36	29.8		
Total		121	100.0		

Table 9 exhibits a similar quantitative output as table 8, however the question at hand is inquiring past performance as opposed to present.

Table 10.

Quantitative details of data set pertaining to participant's reading, writing, language, and behaviour against national standard present vs past.

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Improvement	10	8.3	11.5	11.5
	Stable	74	61.2	85.1	96.6
	Decrement	3	2.5	3.4	100.0
	Total	87	71.9	100.0	
Missing		34	28.1		
Total		121	100		

Table 10 compares the differences between the participants' present vs past performance on the 4 areas of interest.

Table 11.

Quantitative details of data set pertaining to participant's pure tone audiometry hearing screening results

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	PASS	108	89.3	89.3	89.3
	REFER	12	9.9	9.9	99.2
	Total	121	100.0	100.0	

The table above differentiates those who passed the hearing screening criteria as outlined in section 2.1. The term "REFER" eventuated to a free full diagnostic hearing test provided at the University of Canterbury Speech and Hearing Clinic.

Table 12.

Quantitative details of data set pertaining to participant's tympanometry results on right ear

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	A	83	68.6	68.6	68.6
	As	1	.8	.8	69.4
	Ad	4	3.3	3.3	72.7
	C	17	14.0	14.0	86.8
	CNS	16	13.2	13.2	100.0
	Total	121	100.0	100.0	

Tympanometry results coded to provide insight into middle ear condition.

Table 13.*Quantitative details of data set pertaining to participant's tympanometry results on left ear*

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	A	88	72.7	72.7	72.7
	As	1	.8	.8	73.6
	Ad	3	2.5	2.5	76.0
	C	12	9.9	9.9	86.0
	CNS	17	14.0	14.0	100.0
	Total	121	100.0	100.0	

Table 14.*Quantitative details of data set pertaining to participant's otoscopy results on right ear*

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Clear	100	82.6	82.6	82.6
	Mild Wax	11	9.1	9.1	91.7
	Moderate Wax	4	3.3	3.3	95.0
	Severe Wax	2	1.7	1.7	96.7
	Slightly Pink	1	.8	.8	97.5
	Occluded	1	.8	.8	98.3
	Mild Scarring	2	1.7	1.7	100.0
	Total	121	100.0	100.0	

Upon otoscopic examination for all participants, 7 visual descriptions were used to code and define outer ear and tympanic membrane condition for the sample.

Table 15.*Quantitative details of data set pertaining to participant's otoscopy results on left ear*

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Clear	100	82.6	82.6	82.6
	Mild Wax	11	9.1	9.1	91.7
	Moderate Wax	4	3.3	3.3	95.0
	Severe Wax	1	.8	.8	95.9
	Slightly Pink	1	.8	.8	96.7
	Bubbles Behind	3	2.5	2.5	99.2
	Ear Drum				
	Mild Scarring	1	.8	.8	100.0
	Total	121	100.0	100.0	

Table 16.

Table displaying continuous data co-variables presented through descriptive statistics

Potential Predictor Variable	N	Minimum	Maximum	Mean	Std. Deviation
Decile	120	3.00	10.00	6.6417	2.02005
Age at Present (Y.M)	101	5.11	13.00	9.5209	1.90113
Household Income	44	25000	300000	120568.18	60266.616
TEAP Score Mean	78	-10	10	5.59	3.805
Valid N (listwise)	31				

3.3.1 TEAP score vs UCAST-FW performance

Keat (2016) sought to assess the validity of teacher rated questionnaires to screen for auditory processing disorder in children in Aotearoa, New Zealand. The study investigated the efficacy of the TEAP from 151 children who attended an audiology clinic, with an additional 18 children making up the sample who were believed to not have concerns with auditory processing. The table below, adapted from Keat (2016), displays the descriptive statistics for TEAP normative and clinical groups.

Table 17.

Descriptive statistics for TEAP normative and clinical groups adapted from Keat (2016)

Measure	Typically developing		Clinical	
	Mean (SD)	Median	Mean (SD)	Median
TEAP Factor 1 – Complex Listening	2.16 (.92)	4.00	-3.76 (.294)	-4.00
TEAP Factor 2 – Easy Listening	1.16 (.47)	2.00	-1.35 (.21)	-1.00
TEAP Factor 3 – Speech and Language	2.83 (.16)	3.00	1.84 (.09)	2.00
TEAP Total	6.16 (1.37)	9.00	-3.27 (.48)	-3.00

As derived from the normative sample within Keat's study, the TEAP Total mean subtracted by 2 standard deviations provided a threshold of separation between individuals scoring at or below typical performance; this TEAP total came to 3.42.

Based on this number, a scatter plot comprising of the whole data set has been graphed to demonstrate the spread of UCAST-FW binaural performance with respect to the differentiation between participants who scores at or below the 3.42 threshold.

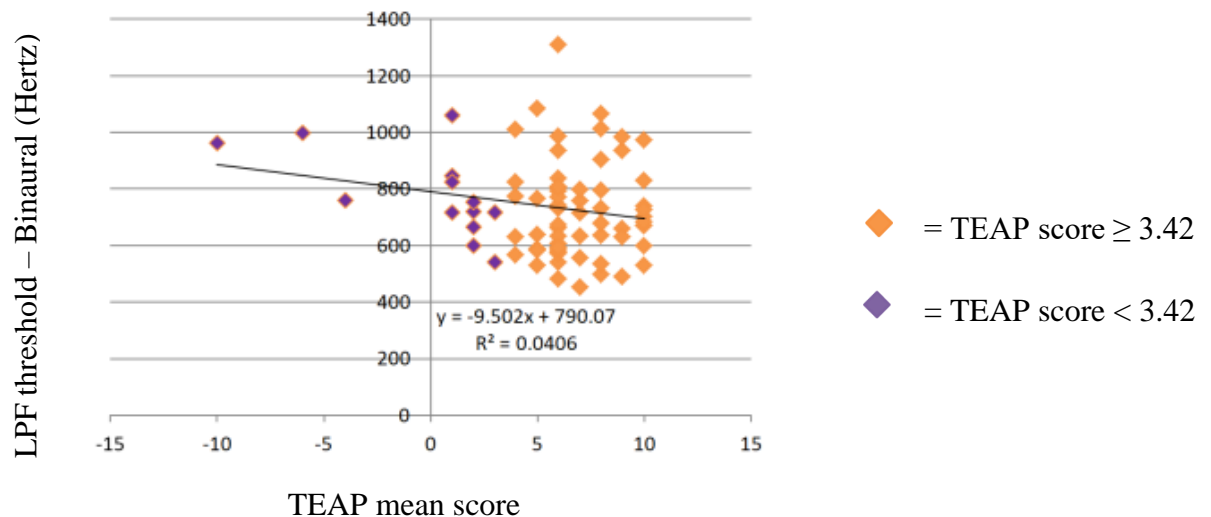


Figure 9: Scatter plot displaying participant's Teacher Evaluation of Auditory Performance (TEAP) mean score against their low-pass-filter (LPF) threshold on the UCAST-FW under binaural condition with r-squared value

3.3.2 TEAP vs RE and LE

The figures below display the spread of UCAST-FW scores with respect to Teacher Evaluation of Auditory Performance (TEAP) total mean score.

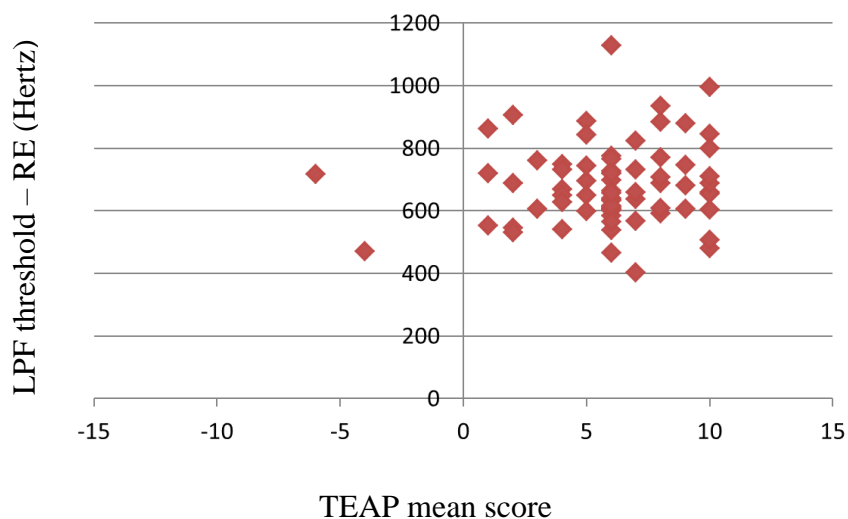


Figure 10: Scatter plot displaying participant's Teacher Evaluation of Auditory Performance (TEAP) mean score against their low-pass-filter (LPF) threshold on the UCAST-FW under the monaural right ear (RE) only condition

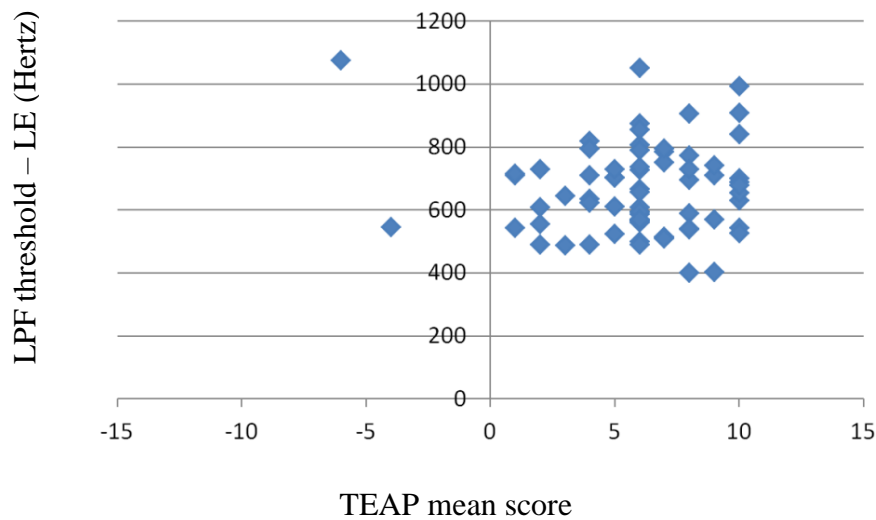


Figure 11: Scatter plot displaying participant's Teacher Evaluation of Auditory Performance (TEAP) mean score against their low-pass-filter (LPF) threshold on the UCAST-FW under the monaural left ear (LE) only condition

3.4 Age vs UCAST-FW performance

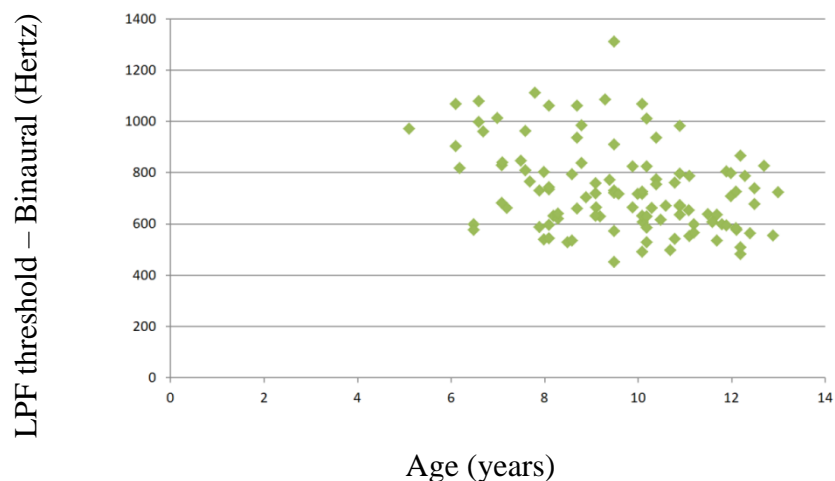


Figure 12: Scatter plot displaying participant's age in years against their low-pass-filter (LPF) threshold on the UCAST-FW under the binaural condition

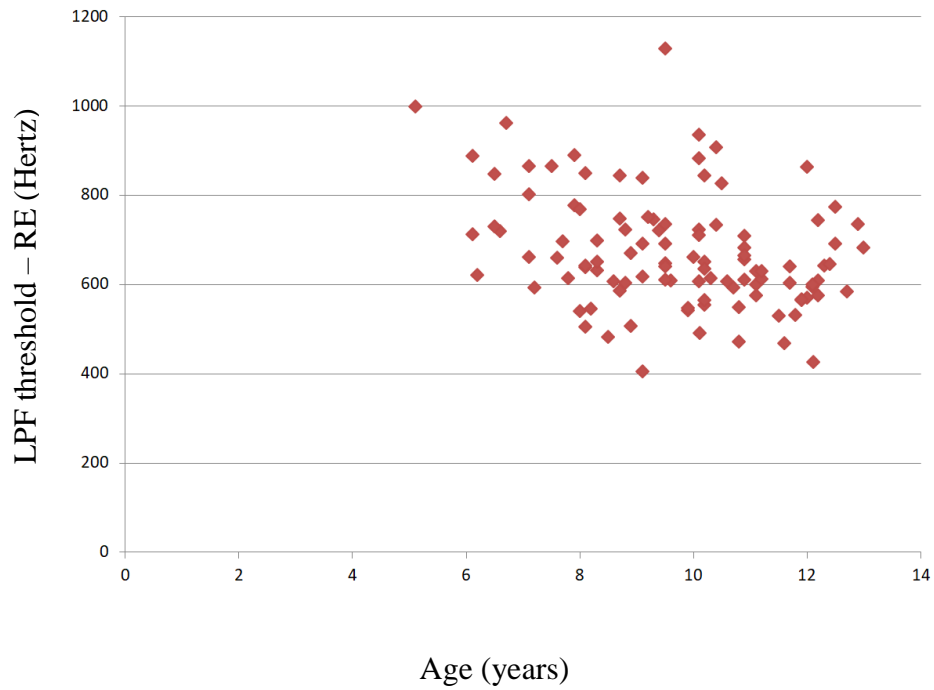


Figure 13: Scatter plot displaying participant's age in years against their low-pass-filter (LPF) threshold on the UCAST-FW under the monaural right ear (RE) only condition

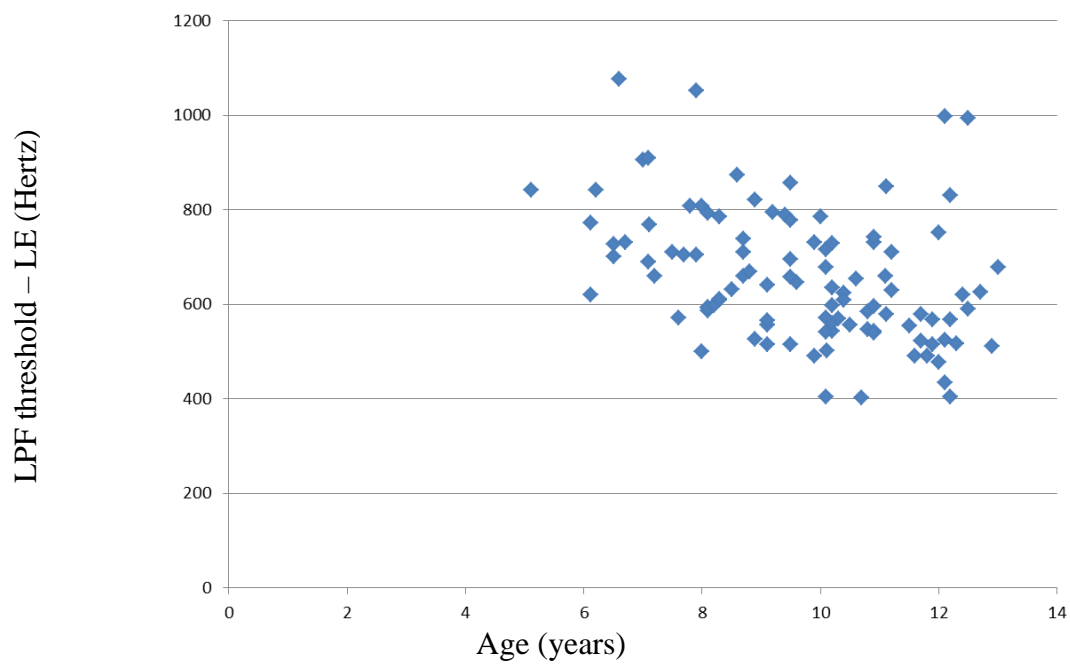


Figure 14: Scatter plot displaying participant's age in years against their low-pass-filter (LPF) threshold on the UCAST-FW under the monaural left ear (LE) only condition

3.5 Overview of Analysis

Regression Analysis: Multiple general linear regression models serve to organise the proportional impact of potential predictor variables on the variable of interest (Becker & Chambers, 1984). The regression analysis served to identify the significant potential predictor variables on the UCAST-FW performance based upon the quantitative information provided by either the participant's teacher or guardian/parent. Isolating and separating the impact of covariates would be an essential first step in discovering the relationship between age and UCAST-FW performance which is the main dependent variable of interest in this study.

With the assumption that age would be a significant predictor variable, as per analysis from the regression, a cluster analysis was then performed in order to find natural groupings of participants by different age groups based on UCAST-FW performance. This step provided more meaningful comparisons between age groups than simply comparing UCAST-FW performance across fixed age brackets. As mentioned in chapter 1, the neural maturation of the CANS could be observed from the age of 6 until adolescence (Ponton et al., 2000); however the literature did not mention the degree of maturation as age increased. Similarly as it could not be assumed that there were significant differences between each age group by year, UCAST-FW performance would be treated as the variable that informed decisions on age grouping, not the other way around.

Finally, based on the age groups defined by the k-mean cluster analysis, an ANOVA was performed to examine between age group differences of UCAST-FW performance.

3.6 Regression Analysis

A multiple linear regression analysis was performed in order to determine the significant predictor variables of UCAST-FW performance. The potential predictor variables involved in this statistical analysis were: age at testing, decile, past and present reading, writing, language, and behaviour performance at school, and mean score derived from the teacher evaluation on auditory performance (TEAP) questionnaire. The remaining quantitative information including English as first language, other languages spoken, proficiency, and additional conditions/services were not included in the regression as the dataset showed expected normative results and lacked the variation of range among participants to be deemed as a meaningful predictor variable to include in the analyses.

Furthermore, household income was revoked from the analyses due to only 33.6% of participants disclosing their annual household income on the parent questionnaire. This was replaced with the New Zealand decile ratings updated from 2015 by which data was obtained for 97.9% of participants. Deciles are a measure of the socio-economic position of a school's student community relative to other schools throughout the country. Although deciles do not indicate the specific socio-economic status of each child within the school; it does however utilise quantitative information provided by Statistics New Zealand on household income, occupation, household crowding, educational qualification, and income support in order to calculate the decile rating of the school (Gordon, 2015). With the dependent variable being the Binaural 62.5% weighted up/down staircase (WUDR) threshold, a stepwise regression was used (p-level to enter: $\leq .05$, p-level to remove $\geq .10$).

With multiple linear regression analysis, there are several key assumptions that the data-set must meet.

- Firstly, there must be a linear relationship between the independent and dependent variables which can be illustrated through scatterplots being linear or curvilinear in relationship. P-P plots were performed to examine linearity as shown below in figure 15.

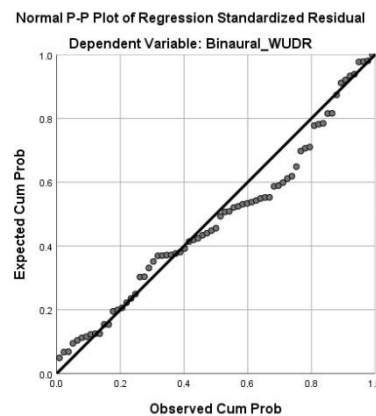


Figure 15: P-P Plot of Regression Standardized Residuals

- Secondly, multiple regressions assume that the residuals are normally distributed. From the data, normality of residuals was tested and was found not to be significant.
- Another assumption states that the independent variables are not highly correlated with one another. This is the assumption of collinearity and can be assessed using the Variance Inflation Factor (VIF) values. The assumption of collinearity was not violated ($VIF = 1.00$). Furthermore, a significant component to the compliance of this assumption was due to the design of this study. It was understood that in order to perform a regression analysis, the data collected on potential predictor variables needed to be independent from one another.

- The final assumption is homoscedasticity. This is the assumption that the variance of error terms is not dissimilar across the values of independent variables. Essentially error terms are defined as the degree to which the error variance is random or the equality of distribution (Jamshidian & Jalal, 2010). A plot of standardized residuals versus predicted values can demonstrate the equality of distribution across all values of the independent variables. This essentially assesses the variance along the regression line to ensure that it is random. It was found that the dataset did not violate this assumption.

It should be stated there was a notable reduction in sample size as the regression requires each participant to have complete data across all potential predictor variables in order to qualify for analysis. This resulted in 71 participants entering the regression analysis by which the predominant variable lacking data was the TEAP score.

From the regression analysis, it was found that only 1 variable significantly predicted Binaural score: Age ($p = .001$). The regression equation is as follows: $Y' = -.403 (\text{age}) + 983.12$. $R^2 = .162$. This means that when age is considered as a predictor variable, any additional potential predictor variables will not add any further prediction ability than compared to age alone.

3.7 Cluster Analysis

As mentioned above, the k-mean cluster analysis was performed to determine the age grouping that best defined the sample. This had the advantage of increasing the statistical power of the ANOVA. The grouping variable was age at testing. The k-mean cluster analysis

is the most frequently used clustering technique to optimize datasets; however reliability can be affected by the entrapment in local data minima.

For instance, the overall result can be influenced by the initial cluster centres (K.-j. Kim & Ahn, 2008). Thankfully this issue can be resolved through SPSS by performing many iterations to derive the final cluster centres.

The final cluster centres are shown as descriptive statistics in the table below:

	Min	Max	Mean	SD
Youngest (N = 35)	5.11	8.30	7.34	.81
Middle (N = 44)	8.50	10.60	9.59	.63
Oldest (N = 36)	10.70	13.00	11.72	.66

Table 18.

Despite the regression analysis utilising 71 participants, the cluster sample size increased to 115 because only performance on the binaural UCAST-FW data and age were required to perform this analysis.

3.8.1 ANOVA

Using these cluster groups, an ANOVA was performed. It was found that a univariate analysis of variance (ANOVA) would be sufficient as no other significant predictor variables were found other than age of participant as per the regression analysis; thereby prompting the decision to choose the ANOVA over the ANCOVA. A univariate analysis of variance was performed with the binaural score being the dependent variable whilst age cluster was the grouping factor. No covariates were used. Levene's test of equality of error variances was not

significant ($p = .06$), so this assumption was not violated. The table below shows the descriptive statistics for the binaural scores for each of the three age clusters.

	Mean	SD
Youngest (N = 31)	797.66	176.87
Middle (N = 43)	747.87	180.02
Oldest (N = 35)	664.67	117.74

Table 19.

Table showing mean distribution of binaural UCAST-FW score between the age groups of youngest, middle, and oldest

There was a significant main effect of age on binaural scores: $F(2,106) = 5.78, p = .004, \eta^2 = .098, 1 - \beta = .86$. Post-hoc testing revealed significant differences between the oldest and middle cluster ($p = .026$) and between the oldest and youngest cluster ($p = .001$), but not between the middle and youngest cluster ($p = .19$).

The findings above does therefore support the hypothesis that the maturation of the CANS has an impact on the auditory processing performance when administering and observing the UCAST-FW scores between age groups

3.8.2 ANOVA Monaural Conditions

Although the ANOVA statistical analysis was still performed, it should be noted that there are discrepancies between the number of data points obtained between the binaural and monaural conditions. This was predominantly due to fatigue and examiner effects which will be discussed in greater detail in section 6.4.

Monaural Right Ear Condition

	Mean	SD
Youngest (N = 28)	726.58	130.11
Middle (N = 42)	581.03	138.50
Oldest (N = 35)	616.85	86.95

Table 20.

Table showing mean distribution of monaural right ear UCAST-FW score between the age groups of youngest, middle, and oldest

Post-hoc testing revealed significant differences between the oldest and middle cluster ($p = .023$) and between the oldest and youngest cluster ($p = .001$), but not between the middle and youngest cluster ($p = .127$).

Monaural Left Ear Condition

	Mean	SD
Youngest (N = 29)	733.52	138.45
Middle (N = 43)	644.80	110.32
Oldest (N = 35)	610.33	143.68

Table 21.

Table showing mean distribution of monaural left ear UCAST-FW score between the age groups of youngest, middle, and oldest

Post-hoc testing revealed significant differences between the middle and youngest cluster ($p = .007$) and between the oldest and youngest cluster ($p < .001$), but not between the middle

and oldest cluster ($p = .259$). A mixed model ANOVA was performed to test the effect of participant age and administration ear.

Age consisted of 3 levels, as defined by the cluster analysis: younger, middle, and older. The levels pertaining to the ear were left, right, and binaural. Mauchly's test was not significant so sphericity was assumed ($p = .70$). There was no significant interaction between age and ear: $F(4, 194) = .775$, $p = .54$. The simple main effects of ear and age were examined. The mixed model ANOVA revealed a significant effect of administration ear: $F(2,194) = 7.65$, $p = .001$, $h^2 = .07$. Post hoc pairwise comparisons revealed a significant difference between the binaural condition and both monaural conditions (right ear $p = .005$; left ear $p = .001$). There was no significant difference between the two monaural conditions ($p = .35$)

3.9 Post-Hoc Analysis of Reversal for the UCAST -FW

In order to analyse the change in UCAST-FW score as a function of the number of reversals carried by the participant, a number of statistical analyses were performed. Firstly, the condition for analyses was the binaural run as this yielded the greatest number of data points to improve statistical significance. This data was further cleaned up to remove missing data points and the sample size clusters are as follows:

Sample Groups	Sample Size
Cluster 1	35
Cluster 2	15
Cluster 3	53
TOTAL Sample Size	103

Table 22.

Sample size for group clusters in post-hoc analysis of reversals for the UCAST-FW

Descriptive and boxplots found no significant deviation from normality thereby permitting the performance of a mixed-model ANOVA; of which Cluster Group was between measure and Binaural (5, 10, and 15) was the repeated measure.

The effect size was calculated to obtain Cohen's d values. From this, a Box's Test of Sphericity was performed and found to be significant ($p < .001$), therefore a Greenhouse-Geisser correction was implemented in the analyses for the repeated measure.

Subsequently, there was no significant interaction of group and binaural: $F(4, 200) = 1.6$, $p = .73$, $\eta^2 = .03$. There was also no significant main effect of the between measure (Cluster group): $F(2, 100) = 2.48$, $p = .08$, $\eta^2 = .05$. Therefore, posthoc analyses were not required.

However there was a significant main effect of the repeated measure (Binaural): $F(1.1, 11.2) = 16.63$, $p < .01$, $\eta^2 = .15$. Posthoc analyses indicated *significant differences on all comparisons* based on the repeated measure:

- i. Binaural (5) vs. Binaural (10): $p < .001$, $d = .17$
- ii. Binaural (5) vs. Binaural (15): $p < .001$, $d = .26$
- iii. Binaural (10) vs. Binaural (15): $p = .004$, $d = .10$

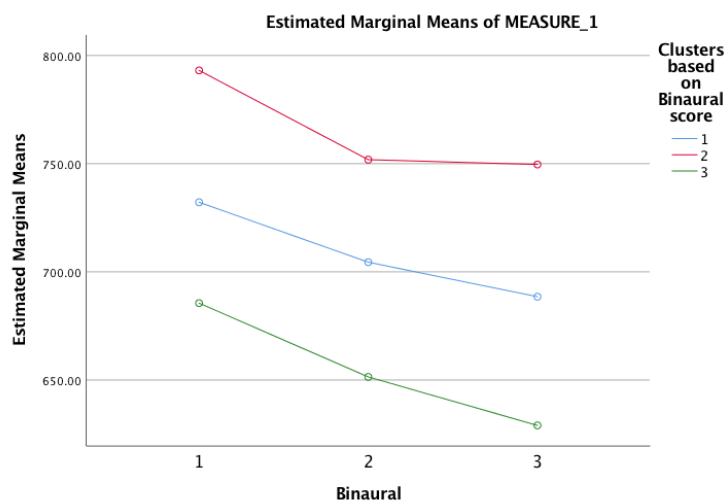


Figure 16: Profile Plot showing change in mean UCAST-FW score as a function of number of reversals

As exhibited in figure 16 above, the vertical axis represents the mean scores on the DV. The horizontal axis represents the repeated measure {Binaural 1 = Binaural (5). Binaural 2 = Binaural (10). Binaural 3 = Binaural (10)}. The lines represent the between factor (Cluster Group).

As shown by the plot above, the lines are relatively parallel. This graphically depicts the lack of a significant interaction between the factors (cluster group and repeated scores). That is, all 3 groups performed similarly on the repeated measure.

There is separation between the lines (which represent the 3 cluster groups). While this factor was not significant in the analysis, the effect size indicated that 5% of the variance in scores can be attributed to cluster group. The lack of statistically significant findings may be related to the sample size (underpowered). For example, cluster group 2 only had 15 participants.

The downwards trajectory of each line indicates the effect of the repeated measure, which was significant at each interval. This was the main finding: 15% of the variance in the model can be attributed to this repeated measure. This analysis was sufficiently powered, as all 103 participants contributed to this analysis.

Chapter Four:

Discussion

4.1 Effects of participant age on UCAST-FW performance

The present study examined the maturational effect of age on the CANS thereby influencing performance on the UCAST-FW among children from the age of 6 to 12 years old. It was hypothesised that upon performing an ANOVA statistical analysis between UCAST-FW score under the binaural condition and the age groups derived from the k-mean cluster analysis, there would be a significant main effect of age on binaural scores. The study findings supported this hypothesis, with a significant main effect of age on binaural scores: $F(2,106) = 5.78, p = .004, \eta^2 = .098, 1 - \beta = .86$. Post-hoc testing revealed significant differences between the oldest and middle cluster ($p = .026$) and between the oldest and youngest cluster ($p = .001$), but not between the middle and youngest cluster ($p = .19$).

These findings support the hypothesis that there the maturation of the CANS has an impact on auditory processing performance and opens the conversation on the theory that the development of the CANS is non-linear as the effects of maturation are more apparent when comparing the middle group to the oldest group and not between the middle and youngest group. In addition, a multiple linear regression analysis was performed in order to determine the significant predictor variables of UCAST-FW performance. Subsequently, it was found that only 1 variable significantly predicted Binaural score: Age ($p = .001$). The regression equation is as follows: $Y' = -.403 (\text{age}) + 983.12, R^2 = .162$. This means that when age is considered as a predictor variable, any additional potential predictor variables will not add any further prediction ability than compared to age alone.

This regression analysis thereby further consolidated the validity of the ANOVA analysis as age was known to be the only statistically significant predictor variable associated to UCAST-FW performance. These combined results with the existing understanding of the association between the myelination of the auditory system and growth of dendritic branching structures resulting in improved auditory processing abilities (Hallett & Proctor, 1996) provide further evidence that the maturation of the CANS has a significant effect on participant performance on the UCAST-FW when comparing those from 6 to 12 years of age.

4.2 Comparison of results with past research – Age vs UCAST-FW Score

Among the various preceding dissertations on the UCAST-FW, the most relevant sample of comparison in context to this study would be McGaffin (2007) study on the development of monosyllabic adaptive speech test for the identification of central auditory processing disorder. From his study, 26 children with normal auditory processing were recruited with a range of 9 to 11 years with a mean age of 9.9 (± 1.3 years). Direct quantitative comparisons could not be made due to the discrepancy between the statistical analyses performed in each respective thesis. However participant performance on the binaural condition can be compared when lining up McGaffin's analyses grouped by year and the k-mean cluster groupings as shown below

Table 23. Mean UC MAST threshold scores for each age group. Values in brackets are standard deviations and all values are in Hertz. Adapted from McGaffin (2007)

Age group / UC MAST test condition	7 years (n = 2)	8 years (n = 5)	9 years (n = 9)	10 years (n = 9)	11 years (n = 7)
Binaural 50% (Hz)	768 (±89)	1249 (±360)	937 (±191)	890 (±247)	886 (±252)

When comparing the three cluster groups, the youngest group can be lined up with the 7 years group, middle group with 8 and 9 years, and oldest group with 10 and 11 years old. The table below illustrates the discrepancies between this current studies' findings and McGaffin's data collected.

Group Clusters	797 (±168)	747 (±180)		664 (±117)	
	7.33 Years	9.59 Years		11.72 Years	
	(n = 35)	(n = 44)		(n = 36)	
Group by Year	768 (±89)	1249 (±360)	937 (±191)	890 (±247)	886 (±252)
	7 years	8 years	9 years	10 years	11 years
	(n = 2)	(n = 5)	(n = 9)	(n = 9)	(n = 7)

Table 24. Comparison between mean and SD of UC MAST threshold scores for each age group and UCAST-FW results of cluster groupings in current study

Comparisons of the LPF threshold across age groups reveal relatively different frequencies at which the SRT was achieved. The group clusters show gradual improvements in UCAST-FW performance as a function of increasing age whereas McGaffin's spread of LPF threshold reveal that the youngest age group of 7 years in fact perform best out of all age groups up to 11 years old however with such a negligible sample size for 7 year old participants ($n=2$), this comparison would not be statistically significant. An interesting observation contrary to the understanding of improved auditory processing with increased age with the maturation of the CANS. Furthermore, the participants from the current study on the whole performed significantly better than those in the normative sample in 2007. Similar to the current protocols, both theses used the binaural test as a practice session for participants to ensure familiarity with the procedure.

It is important to consider the progression of the UCAST-FW over the past decade as a significant factor as to the changes in performance. As mentioned in chapter 1, Gibbins (2018) made further improvements to the validity and reliability of the UCAST-FW by being the first to recognise the heterogeneity between the test items of the word lists being used in the test. Adjustments to the level of low-pass filtering for each test item in order for performance to be equivalent to the mean performance for the entire word list may have improved the reliability of the test. However it is difficult to determine whether this normalisation process would have made a significant difference between the performance of children aged 6-12 years when comparing the sample of McGaffin's thesis and the current study.

4.3 Comparison of results with past research – Sample performance discrepancies

Although the current study findings support the hypothesis of maturation with a significant main effect of age on binaural scores when performing an ANOVA, a very notable discrepancy in the cut-off frequency for the 62.5% midpoint of the psychometric function can be seen between a preceding study done by Rickard et al. (2013), where they hypothesized children with APD would require a significantly wider band of frequencies present in a speech signal compared to control children, in order to comprehend a monosyllabic speech signal. This particular study recruited a control group (n = 10) of children without auditory processing or learning difficulties from various local primary schools. The demographic qualities of these participants match this current study's sample as well as the UCAST-FW test procedure being similar in test order with differences being in the number of reversals recorded before the cut-off frequency calculated. In fact, the participants in Rickard et al.'s study were also required to complete a peripheral hearing assessment as well as an auditory processing test battery consisting of the DDT, FPT, and SCAN-C FW. Compared to the current study, Rickard et al.'s test battery would've had significantly more fatigue effects on the participants thereby presumably causing decrements in UCAST-FW performance; however the more important point of discussion becomes evident when analysing the results.

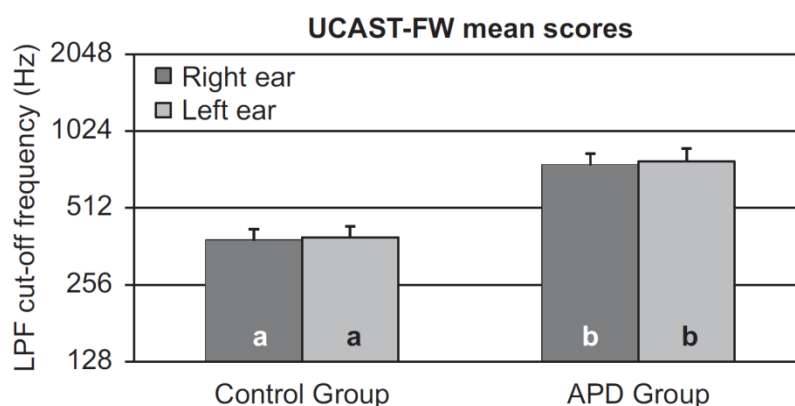


Figure 17: Mean UCAST-FW scores (following 20 reversals at the working increment) for the right and left ears for Control and APD groups adapted from Rickard et al. (2013)

For the control group, the mean UCAST-FW score for the right ear was 381.7 Hz (\pm 41.3), and for the left ear 393.0 Hz (\pm 40.9). In contrast, the APD group participants yielded a mean UCAST-FW score of 752.3 Hz (\pm 84.4) for the right ear, and 777.8 Hz (\pm 96.6) for the left ear. The results from Rickard et al.'s study show significantly better UCAST-FW scores compared to that of this current study's results. Comparatively, even upon isolating the mean cut-off frequency to the oldest cluster group which is the best performing group due to maturation, there is still an increased cut-off frequency of over 200 Hz in both the right and left ear when compared to the performance of participants in Rickard et al.'s study.

Moreover, the APD group in Rickard et al.'s study is in fact more similar to the current study's "normative" sample. Taking a step back, the wide cut-off frequency differences may have contributing factors beginning at the research design phase. Rickard et al.'s design model had the advantage of thorough participant qualification procedures to ensure that the control group was clinically assessed with an APD test battery prior to commencing the UCAST-FW. This subsequently provided results with inherently more validity than the current study's sample results. The caveat of recruiting over 100 participants within the course of an academic year is the acquisition of quantity at the expense of quality assurance. Not having performed clinical tests to ensure the 'normative' sample was truly within normal limits for central auditory processing, there is a probable chance that several children with auditory processing difficulties may have fallen into the sample despite multiple filtering mechanisms from teacher and parent feedback questionnaires. This limitation will be discussed in greater detail in chapter 6.

4.4 Comparison of results with past research - Potential predictor variables influence on CAP

The objective of recruiting over one hundred participants within the course of one academic year posed various challenges pertaining to staying within the constraints of the inclusion criteria in order to obtain a normative sample. Two possible courses of action could be taken to overcome this. Firstly, the sterile method would be to have every participant complete an APD test battery prior to commencing involvement in the UCAST-FW. However this would not have been feasible with the time constraints given, furthermore logistically this would have made recruiting in schools more challenging and time consuming. Therefore quantitative questionnaires were administered to the participant's respective parent/guardian and school teacher in order to evaluate potential predictor variables that may have an impact on central auditory processing performance. Although recruitment outreach had specifically requested for children with no neurological, or auditory processing difficulties, it was conservatively considered that certain covariates may have some influence on the UCAST-FW performance.

All information provided from the participants' parents and teacher in corroboration with the data collection from the UCAST-FW was then analysed post-hoc to evaluate any statistical significance among the potential predictor variables of the following: Decile, past and present reading, writing, language, and behaviour performance at school, and mean score derived from the TEAP questionnaire. In short, the regression analysis only supported the variable that significantly predicted Binaural score was Age ($p = .001$). This in turn suggests that any additional potential predictor variables as will not add any further prediction ability than compared to age alone. However further investigation into the various potential predictor variables although not statistically significant, may still offer valuable insight into the

demographic trends related to the prevalence of APD. Two areas of discussion can be seen in decile rating and TEAP score.

As mentioned in chapter two, evidence for associations between literacy difficulties and lower socio-economic backgrounds have been linked to increased risk of ADHD which has often been found to have comorbidity with APD (Carroll et al., 2005). Comparing the literature's stance on this association with the results produced from the regression analysis, as mentioned earlier in chapter 3, it was found that only 1 variable significantly predicted Binaural score: Age ($p = .001$). The association between the participant's school decile and their UCAST-FW performance was therefore not deemed to be statistically significant.

However an interest point of discussion is that Nagao et al. (2016) found that the more probable reason for children in private schooling having greater prevalence of APD compared to children who attended public schooling was due another correlated association. Further investigation revealed that the connection was in fact between a higher proportion of Caucasian children being referred for APD evaluation and coincidentally also making the majority of private schooling sector. The study suggested that more children among those in public schools were of Hispanic and African American descent whom should have been referred for APD evaluation but was not due to a lack of awareness of clinical resources among families within those demographic groups. This thereby prompts attention to be focused more on the association between ethnicity and prevalence of APD. Unfortunately as mentioned in chapter 3, the remaining quantitative information including ethnicity were not included in the regression as the dataset showed expected normative results and lacked the variation of range among participants to be deemed as a meaningful predictor variable to include in the analyses. With 74.4% of the sample size being European, the spread of variation was not sufficient enough.

The relationship between the TEAP mean and UCAST-FW performance as shown in figure 10 provides a statistical measure of how close the data are to the fitted regression line. Upon visual observation, it does appear as though a negative correlation has developed between increasing TEAP score with decreasing UCAST-FW corner frequency. However the R^2 value provides a percentage of the response variable variation that is explained by a linear model. The 0% end indicates that the model explains none of the variability of the response data around its mean whereas 100% suggests that the model explains all of the variability of the response data around the mean. With an R^2 value of 0.0406, there is insignificant predictability of UCAST-FW score as a function of TEAP score. However this was somewhat expected as the TEAP score was completely predicated on subjective human behaviour. Furthermore, the multiple linear regression analysis results indicated that TEAP was not considered to be a predictor variable of UCAST-FW performance. It is difficult to objectively compare the findings from authors such as (Barry et al., 2015; Purdy et al., 2002) due to the lack of similarity in APD test batteries as the UCAST-FW is a relatively novel approach to detecting abnormalities in CAP.

4.5 Ear Differences

Findings from (Abu-Hijleh, 2011; McGaffin, 2007) both show no significant ear advantage based on monaural UCAST-FW scores for adult participants. These results still hold true from this current study as no The mixed model ANOVA revealed no significant difference between the two monaural conditions ($p = .35$). However post hoc pairwise comparisons did reveal a significant difference between the binaural condition and both monaural conditions (right ear $p = .005$; left ear $p = .001$). This was presumably due to the binaural condition always coming first in the test procedure with the culmination of a practice phase thereby suggesting learning or fatigue effects may have had some impact on UCAST-FW scores

between conditions; this will be discussed in section 4.6. As previously mentioned by previous theses authors such as Abu-Hijleh (2011), a limitation that still persists in the current version of the UCAST-FW program is the absence of control over contralateral masking noise when necessary. With the speech stimulus presented at 65 dBA and presumable 40 dB of interaural attenuation provided with supra-aural transducers, there is a probable chance that the speech signal may have crossed over to the non-test ear. Considering participants included in this analyses had good peripheral hearing without middle ear disorders, this further adds to the likelihood of possible inaccurate UCAST-FW scores between monaural conditions. Improvements to the test procedure to mitigate such issues will be discussed in greater detail in chapter 6.

4.6 Effects on UCAST-FW Performance

The main area of interest regarding learning effects is between the binaural conditions and the summing mean performance on the monaural conditions for the UCAST-FW. This is because the binaural condition included a practice run of 15 practice runs, with the easiest practice low-pass filter frequency at 1000 Hz progressively decreasing to 400 Hz.

Furthermore, because the binaural condition in every participant was the first of 3 UCAST-FW runs; this always succeeded the explanation phase of the testing procedure. Two schools of thought arise from this, firstly it could be speculated that the first run of the UCAST-FW regardless of condition will generally be the worst performing of the three simply because the participant is still unfamiliar with the task and may still be apprehensive, second guessing themselves thereby making careless mistakes.

However the contrary opinion may suggest that the advantageous effects of working memory from being just exposed to explanation phase prior to commencing the binaural run may result in better UCAST-FW performance compared to the monaural conditions. Furthermore this opinion questions the equality of attention between conditions. With at least 15 reversals required in each condition, it can be assumed that a reasonable degree of cognitive demand is required to consistently perform well across all 3 conditions (summing to about 15 minutes in test time). Essentially, this is the thought that the decremented fatigue effects would outweigh the advantages of learning experience thereby leading to poorer monaural UCAST-FW scores compared to the binaural condition.

Because the monaural conditions between right and left ear were counterbalanced for all participants, the main comparison of interest is between binaural and averaging monaural mean cut-off frequency.

The mixed model ANOVA revealed a significant effect of administration ear: $F(2,194) = 7.65$, $p = .001$, $h^2 = .07$. Post hoc pairwise comparisons revealed a significant difference between the binaural condition and both monaural conditions (right ear $p = .005$; left ear $p = .001$).

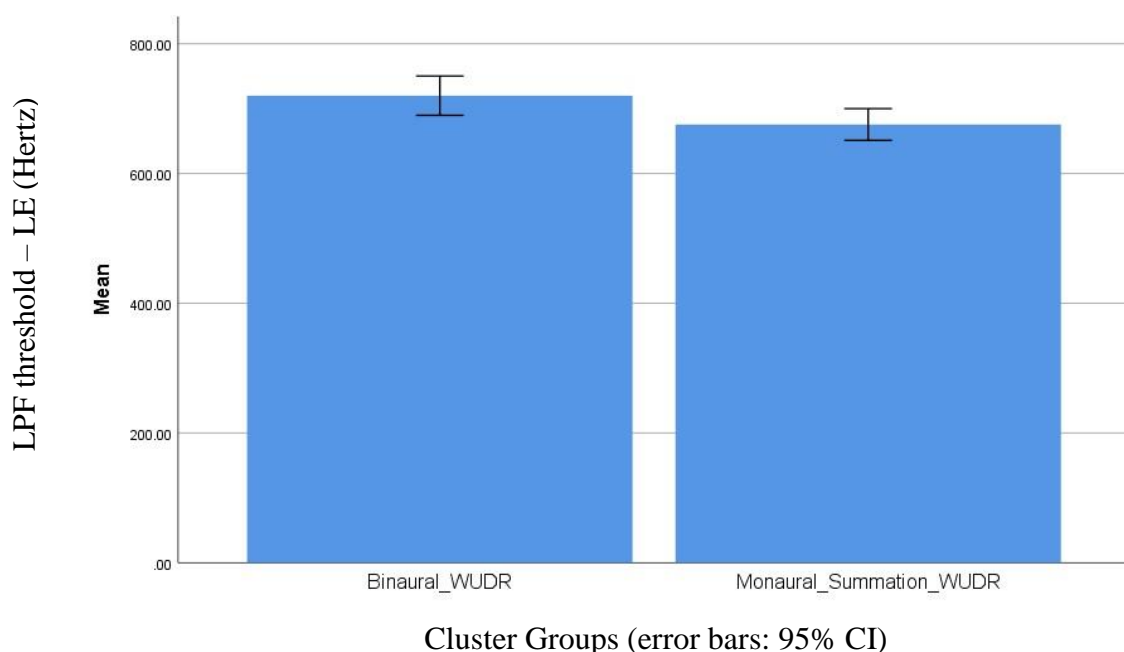


Figure 18: Bar graph showing mean distribution of binaural UCAST-FW score between binaural condition and the mean of monaural condition data set (RE and LE)

The results shown above fall in favour of the potential influence of learning effect taking place as the monaural conditions' mean was only 667.23 Hz (SD = 133.42) compared to the binaural condition's mean of 741.10 Hz (SD = 167.13). Not only does the monaural condition yield an improvement of cut-off corner frequency by 73.87 Hz compared to the binaural condition, but it also produces less variation with a lower standard deviation from the mean.

This suggests that learning effect may be yielding more consistent results among participants as the majority of them reach a state of understanding that is not dissimilar from one another thereby leading to less intragroup variability.

This improvement of decreased intragroup variability as a function of experience and time for each participant can also be seen in a study by O'Beirne et al. (2012) whereby the more number of reversals the participant went through, the more narrow the frequency bandwidth was between reversals; thereby leading to its final low-pass filter threshold.

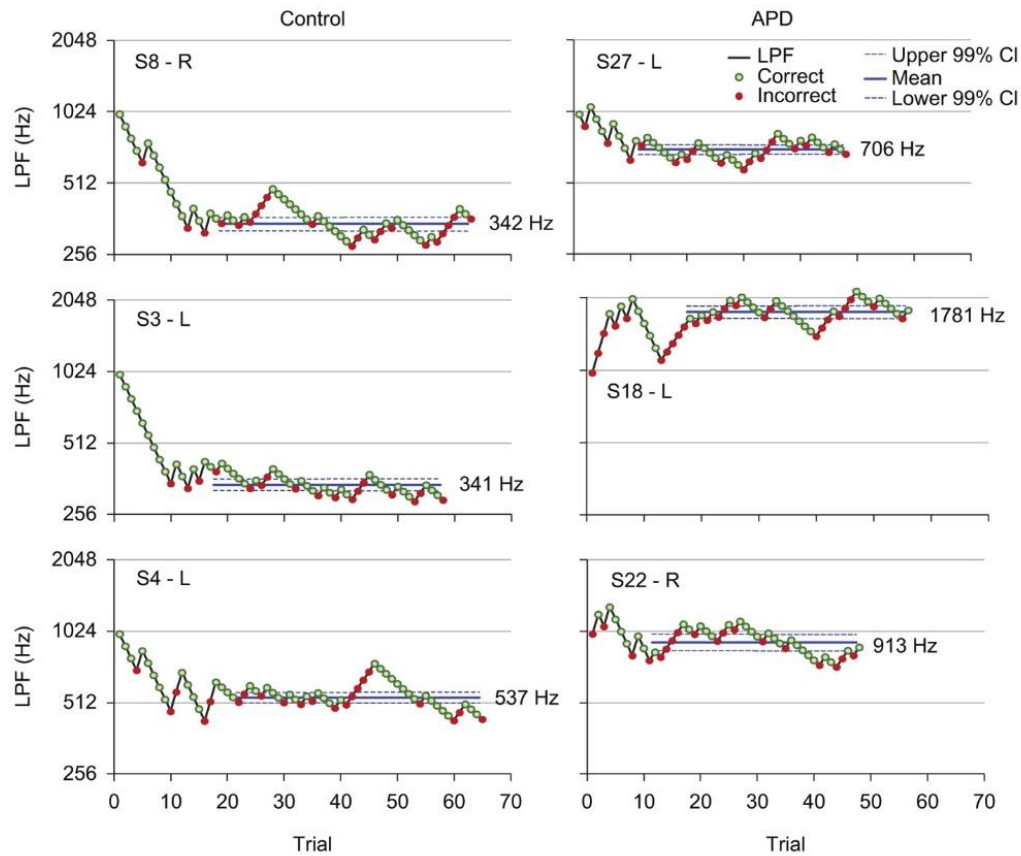


Figure 19: Representative UCAST-FW adaptive tracks from three control participants (left hand panel) and three APD group participants (right hand panel). The 62.5% WUDR estimate is given by the Mean line, and the 99% confidence intervals, calculated on log-transformed data, are shown as dashed lines about the Mean adapted from (O’Beirne et al., 2012).

5. Conclusion

5.0 Conclusion

Within this study, the maturation effect of age on UCAST-FW performance was assessed among 143 children participants with normal peripheral hearing, no neurological impairments, and supposedly normal auditory processing ranging from 6 to 12 years of age. Upon removal of outliers, 121 participants remained in the final analyses. This observation of improved UCAST-FW score (i.e decreasing corner-frequency) with increasing age was observed in previous studies by O'Beirne et al. (2012) and McGaffin (2007). Although the results were not consistent with past research, there was still an overall maturational effect observable between age and UCAST-FW performance. Furthermore, this study aimed to understand the impact of potential confounding variables such as decile, past and present reading, writing, language, and behaviour performance at school, mean score derived from the teacher evaluation on auditory performance (TEAP) questionnaire, English as first language, other languages spoken, proficiency, and additional conditions/services.

The impact of these potential predictor variables were analysed via the performance of a regression analysis by which only age was significantly predicted Binaural score: Age ($p = .001$). The regression equation is as follows: $Y' = -.403 (\text{age}) + 983.12$. $R^2 = .162$. A k-mean cluster analysis was performed to determine the age grouping that best defined the sample to which an ANOVA analysis revealed a significant main effect of age on binaural scores: $F(2,106) = 5.78$, $p = .004$, $\eta^2 = .098$, $1 - \beta = .86$. Post-hoc testing revealed significant differences between the oldest and middle cluster ($p = .026$) and between the oldest and youngest cluster ($p = .001$), but not between the middle and youngest cluster ($p = .19$).

These results support the existing understanding of the development of the CANS in children from infancy to adolescence. The ultimate objective behind collecting normative data is to one day creating correction factors to compensate for the maturational effect of age on UCAST-FW performance, however more data will need to be collected by which this dissertation was purposed to build the infrastructure for normative data collection.

6. Limitations and Future Direction

The present study found a number of limitations involving recruitment, participants, the stimuli, test procedure, and the lack of statistical power.

6.1 Recruitment and Participants

The participants obtained were not a true representation of the New Zealand paediatric population from 6-12. Firstly, financial and human resource constraints meant that recruitment could only be attained regionally within Christchurch. Future theses students within the University of Canterbury may benefit from forming dissertational co-alliances with Masters of Audiology students from the University of Auckland. This would hopefully lead to the acquisition of a more geographically diverse dataset; encompassing the spread of the North and South Island. The rationale behind the recruitment strategy was focused on capturing recruiting as many participants as possible to increase statistical power. Because of this, no specific ratios on ethnic distribution were sought after thereby leaving the inclusion criteria open and uncapped. As seen in table 3, the main ethnicities being European, Chinese, and Māori have a percentage distribution of 74%, 9.9%, and 1.9% respectively.

Fascinatingly, the most recent NZ census reports of 2013 exactly the same percentage of 74% population being of European decent. 12% was reported to be Asian, and 15% Māori.

Although only 1% of the participant sample size identified as primarily Māori, an additional 9.1% of participants identified as “Māori” for their “other ethnicity” as shown in table 4; this therefore could suggest that the sample size was ethnically representative of the New Zealand demographic. However further investigation reveals that of the 12 Asian participants, 10 of them were over the age of 11.

This inherently gave the Asian proportion of participants a maturational advantage for auditory processing which may have countered the effects of having parents who predominantly were not fluent in English thereby posing greater uncertainty as to what the UCAST-FW results can be attributed to. This imbalance of age spread between the Asian and European population was by and large due to an unexpected shortage in 11 and 12 year old participants therefore leading to a third channel of recruitment through Dorayme Music Tuition Studio Ltd.

This was required because of the lack of year group coverage for years 7 and 8 across the four schools tested at. All schools covered years 0-6 which led to an equivalent age spread of 5-10 years old. However only 2 of the 4 schools taught year 7 and 8 students as well which meant that proportionately, there was a shortage of 11 and 12 year old participants to test. Subsequently, only 10 and 5 participants from the ages of 11 and 12 respectively were involved in the study. Fortunately, upon obtaining approval for amendments by the Ethics Committee, additional 4 and 9 participants for the ages of 11 and 12 respectively were gathered through Dorayme Music Tuition Studio Ltd thereby levelling out a more symmetrical distribution of participants across age groups.

Although statistically sound, the caveat of disproportionate ethnicity with age mentioned earlier makes the third channel of recruitment slightly disadvantageous. In hindsight, more attention should be given to the desired number and age spread of participants when deciding on schools to contact and whether they can sufficiently accommodate for the forecasted sample size. Essentially if this was done before the data-collection phase, requests to the combined primary and intermediate schools for a higher number of year 7 and 8 participants could help put the sample size age distribution back into balance without sacrificing on ethnic distribution.

6.2 UCAST-FW Software

The UCAST-FW software has taken on great improvements through its various predecessors producing increased reliability and validity. However, one notable factor of vulnerability remains to be the foil response of the NUCHIPS stimuli. As mentioned in section 2.4, the NUCHIPS is a closed set picture pointing word recognition test for children which is inherently appropriate, however the problem lies in its origins of conception. As these test lists were developed in the United States of America, the arrangement of words and pictures in the foil response was based on phonetical similarities produced by the American accent. The current version of the NUCHIPS pictures and word lists was recording of an Australian dialect speaker (National Acoustic Laboratories, Chatswood, NSW, Australia).

Although slightly closer to the New Zealand accent, this still has not addressed the phonetical differences between American and New Zealand accents thereby invalidating some of the foil responses. For example, the words “ball” and “frog” have phonetical similarities in American English, however when spoken in a New Zealand accent, there is a little similarity which inherently makes it earlier for the participant to distinguish the stimulus word from the other distractor pictures. This caveat has also been mentioned by Gibbins (2018). Efforts by Murray (2012) have been made to resolve this issue as she developed a new four-alternative forced choice test purposed to replace the Northwestern University Children’s Preception of Speech (NU-CHIPS) stimuli that the UCAST-FW had been using. A new word list consisting of 98 sets of four test items was developed in which would be utilised in a closed-set response format for the UCAST-FW. The study described the new word list’s clinical applicability to have potential through further exploration. Work on progressing this new word list progresses; however the current version of the UCAST-FW continues to use the

NU-CHIPS speech stimulus. The hope is that successors of the current UCAST-FW will incorporate the New Zealand adapted wordlist to improve validity.

Due to lack of time and also the very likely impact of fatigue effects, open set was not investigated (only closed) which meant that we could not see observe the similarities or discrepancies between the performance under these two response models. This was observed by Gibbins (2018) when looking at the effect that this had on adults, thus children would be interesting. But we could not do open set either because of the learning effects that this may have in conjunction with the UCAMST-P.

Furthermore, as previously mentioned in section 4.5, the current version of the UCAST-FW lacks the ability to control contralateral masking noise when necessary. Due to the phenomenon of interaural attenuation when testing children with normal hearing, this makes the UCAST-FW vulnerable to overmasking. Future improvements to the testing software may be to introduce a masking setting to the non-test ear when assessing ear specific auditory processing performance. This would hopefully reduce the likelihood of confounding variables of non-test ear contributions to performance thereby increasing validity.

6.3 Testing Environment Limitations

During the data collection phase of this dissertation, the three channels of recruitment yielded varying levels of ambient noise in the test environment which may have caused performance fluctuations between recruitment pools. For participants from Team Tamariki, they were tested in sound treated booths which provided an ambient noise floor of less than 40 dBA during testing procedure; this was the most ideal environment to be in as the stimulus output

level was set to 65 dBA thereby overcoming the potential masking effects of environmental noise.

In contrast, when testing the second recruitment pool of primary schools within central Christchurch, the designated class rooms in the schools offered unfavourable ambient noise levels. External factors for environmental noise came from two sources. Firstly, there would often be times at which the junior division of the school would be released for morning tea whilst testing senior students commenced and vice versa. Without double glassed windows let alone sound treatment in the classrooms, it would at times become very distracting to hear children shouting outside whilst the participant would have to focus harder in order to perform the tasks.

Secondly, due to individual school circumstances, two rooms were not always available for my colleague and me to test separately. Therefore in several cases, the participant's aural feedback to the UCAMST-P would be distracting to the other participant in the same room. The third channel of recruitment through Dorayme Music Tuition Studios although lacking the professional sound treatment of an industry-standard sound booth, had lower ambient noise levels as the participants came were tested on a weekend in which no piano lessons were scheduled. Unfortunately ambient noise levels were not recorded on premises for neither the primary schools nor music tuition studio therefore limitations in this regard are based on qualitative observation.

6.4 Potential Fatigue and Examiner Effects

This present study tested 143 participants with the UCAST-FW and the UCAMST-P; over which time, behavioural observations were made on how the child participants responded to the request for attention over the 45 minute test procedure. Firstly, it is important to preface that the UCAST-FW is certainly time consuming – taking 5 minutes to complete each

condition thereby summing up to at least 15 minutes total completion time. So although repetitive in nature, I believe it is possible to employ strategies of encouragement to keep the participant motivated. Understanding that this was not intended to be a clinical assessment and the participants may opt to terminate the test at any time, it should also be stated that examiner's prompts and style of test administration may have an influence on the uptake of students. Because of this, some practitioners may attain completion of every task on both tests with all participants while others may find it challenging to motivate the children in completing all of the UCAST-FW. Subsequently several participants had missing data for one or more conditions for the UCAST-FW.

Improvements in hindsight should be to communicate clearer and provide mutual understanding on the prompts and level of encouragement to give to the participant thereby reducing on another potential confounding variable. Although in context to this study, a few missing data points have little significance, this may not be so marginal when considering the implications when the circumstances of attempting to properly diagnose a child with potential CAPD. However both my colleague and I agreed that shorter test battery duration for the UCAST-FW would be advantageous especially when considering the context of a full test battery required for APD assessment.

Despite missing data points on the monaural condition due to participant decision to terminate testing on the UCAST-FW, when comparing the cut-off frequency for monaural data points that were obtained vs binaural conditions as exhibited in figure 12 and 15, whatever fatigue effects that may have been contributing to the result were not severe enough to outweigh the learning effects as the monaural conditions appear to be better than binaural. This is further supported with post hoc pairwise comparisons revealing a significant difference between the binaural condition and both monaural conditions (right ear $p = .005$; left ear $p = .001$).

The present study employed behavioural measures to quantify performance. That is, participants had to give a voluntary verbal response. It is widely acknowledged that behavioural paradigms such as the one employed in this study, are not sensitive measures of auditory processing alone because they tap into the listeners higher level cognitive processing of attention, memory, and intelligence (Dawes and Bishop, 2009). Attempts to control for these cognitive factors were to gather quantitative data on reading, writing, language, and behavioural factors from school teachers however was not included in the regression analysis as the dataset showed expected normative results and lacked the variation of range among participants to be deemed as a meaningful predictor variable to include in the analysis. It would be advantageous for future theses on the UCAST-FW to continue investigating the effects that poorer CAP (i.e. decrement in UCAST-FW performance) has on literacy skills at school as this would be clinically useful in cross checking aural reporting from parents and teachers with the UCAST-FW score.

6.5 Lack of Statistical Power for True Normality

As mentioned in chapter 1, section 1.1; collecting normative data that statistically represents the paediatric demographic of New Zealand was simply not feasible due to the financial constraints of two theses students as well as the duration of one academic year. This was not so much an acquired limitation as it was more of an anticipated limitation that was acknowledged from the very beginning. Because of this, over four months of preparation went into planning the research design as the focus was quality over quantity. It was important to consider all possible predictor variables and control of such influences through meticulous quantitative data collection from the participants' parents and teachers. Despite the focus on quality, participant quantity was nonetheless an area to strive towards.

Subsequently, Marie Lay; 2nd year Masters of Audiology student and I collaborated in the

collection of data for the UCAMST-P and UCAST-FW utilising the same participants. This double barrelled testing approach essentially doubled data collection potential and eventuated to the collection of test data for 143 participants. Despite our efforts, testing within central Christchurch still yields normative limitations for geographic spread and therefore greater inter-institutional alliance between universities and academics across the country would be highly beneficial for proving the UCAST-FW's clinical efficacy for national application.

References

- Abu-Hijleh, A. (2011). *Effects of high frequency hearing loss on the University of Canterbury Adaptive Speech Test-Filtered Words (UCAST-FW)* (Master's thesis). Retrieved from <https://ir.canterbury.ac.nz/handle/10092/6112>
- Aitkin, L. (1986). *The auditory midbrain: Structure and function in the central auditory pathway*. New York, NY: Springer Science & Business Media.
- Australian Hearing. (2017). *How to help your child manage central auditory processing disorder*. Retrieved from [https://www.hearing.com.au/Get-help/My-Hearing-App-\(1\)](https://www.hearing.com.au/Get-help/My-Hearing-App-(1))
- Bailey Jr, D. B. (2002). Are critical periods critical for early childhood education?: The role of timing in early childhood pedagogy. *Early Childhood Research Quarterly*, 17(3), 281-294.
- Bamiou, D., Musiek, F., & Luxon, L. (2001). Aetiology and clinical presentations of auditory processing disorders: A review. *Archives of Disease in Childhood*, 85(5), 361-365.
- Bamiou, D., Campbell, N., & Sirimanna, T. (2006). Management of auditory processing disorders. *Audiological Medicine*, 4(1), 46-56.
<http://dx.doi.org/10.1080/16513860600630498>
- Barlow, H. B. (1961). Possible principles underlying the transformations of sensory messages. *Sensory Communication*, 8(2), 217-234.
- Barrett, K. (1995). Auditory disorders in school children. *Ear And Hearing*, 16(6), 637.
<http://dx.doi.org/10.1097/00003446-199512000-00010>

- Barry, J. G., Tomlin, D., Moore, D. R., & Dillon, H. (2015). Use of questionnaire-based measures in the assessment of listening difficulties in school-aged children. *Ear and Hearing, 36*(6), e300.
- Bausell, R. B., & Li, Y.-F. (2002). *Power analysis for experimental research: A practical guide for the biological, medical and social sciences*. Cambridge, England: Cambridge University Press.
- Becker, R. A., & Chambers, J. M. (1984). *S: An interactive environment for data analysis and graphics*. Boca Raton, FL: CRC Press.
- Bellis, T. (2003). Auditory processing disorders. *The Hearing Journal, 56*(5), 10-19.
<http://dx.doi.org/10.1097/01.hj.0000293883.42025.ca>
- Bellis, T. J. (2011). *Assessment and management of central auditory processing disorders in the educational setting: From science to practice*. San Diego, CA: Plural Publishing.
- Black, J. W. (1957). Multiple-choice intelligibility tests. *Journal of Speech and Hearing Disorders, 22*(2), 213-235.
- Bocca, E., Calearo, C., & Cassinari, V. (1954). A new method for testing hearing in temporal lobe tumours: Preliminary report. *Acta Oto-Laryngologica, 44*(3), 219-221.
- Boothroyd, A., & Nitttrouer, S. (1988). Mathematical treatment of context effects in phoneme and word recognition. *The Journal of the Acoustical Society of America, 84*(1), 101-114.
- Calandruccio, L., & Smiljanic, R. (2012). New sentence recognition materials developed using a basic non-native English lexicon. *Journal of Speech, Language, and Hearing Research, 55*(5), 1342-1355.

- Cameron, S., & Dillon, H. (2007). Development of the listening in spatialized noise-sentences test (LISN-S). *Ear and Hearing*, 28(2), 196-211.
- Carroll, J. M., Maughan, B., Goodman, R., & Meltzer, H. (2005). Literacy difficulties and psychiatric disorders: Evidence for comorbidity. *Journal of Child Psychology and Psychiatry*, 46(5), 524-532.
- Chang, E. F., & Merzenich, M. M. (2003). Environmental noise retards auditory cortical development. *Science*, 300(5618), 498-502.
- Chechik, G., Anderson, M. J., Bar-Yosef, O., Young, E. D., Tishby, N., & Nelken, I. (2006). Reduction of information redundancy in the ascending auditory pathway. *Neuron*, 51(3), 359-368.
- Chermak, G., & Musiek, F. (1997). Central auditory processing disorders: New perspectives. *Peripheral Interactions*. San Diego, CA: Singular Publishing Group.
- Christchurch City Council. (2013). Income and deprivation. [online]. Available at: <https://www.ccc.govt.nz/culture-and-community/christchurch/statistics-and-facts/facts-stats-and-figures/economic-standard-of-living/>
- Covey, E., & Casseday, J. H. (1995). The lower brainstem auditory pathways. In A. N. Popper & R. R. Fay (Eds.), *Hearing by Bats* (pp. 235-295). New York, NY: Springer.
- Dodd, G., Wilson, O., Valentine, J., Halstead, M., & McGunnigle, K. (2001). *Classroom Acoustics a New Zealand Perspective*. Paper presented at the 17th International Congress on Acoustics, Rome.

- Dorman, M. F., Sharma, A., Gilley, P., Martin, K., & Roland, P. (2007). Central auditory development: Evidence from CAEP measurements in children fit with cochlear implants. *Journal of Communication Disorders*, 40(4), 284-294.
- Eggermont, J. J., & Ponton, C. W. (2003). Auditory-evoked potential studies of cortical maturation in normal hearing and implanted children: correlations with changes in structure and speech perception. *Acta Oto-Laryngologica*, 123(2), 249-252.
- Elliott, L., & Katz, D. (1979). *Development of Northwestern University children's perception of speech (nu-chips) test*. Auditec. Retrieved from https://www.researchgate.net/publication/270275864_Speech_Perception_Assessments_New_Zealand_SPANZ
- Esplin, J., & Wright, C. (2014). *Auditory processing disorder: New Zealand*. Retrieved from https://www.health.govt.nz/system/files/documents/publications/auditory_processing_disorder.pdf
- Farrer, S. M., & Keith, R. W. (1981). Filtered word testing in the assessment of children's central auditory abilities. *Ear and Hearing*, 2(6), 267-269.
- Fay, R. R. (2013). *The mammalian auditory pathway: Neurophysiology* (Vol. 2). New York, NY: Springer Science & Business Media.
- Ferguson, M. A., Hall, R. L., Riley, A., & Moore, D. R. (2011). Communication, listening, cognitive and speech perception skills in children with auditory processing disorder (APD) or specific language impairment (SLI). *Journal of Speech, Language, and Hearing Research*, 54(1), 211-227.

- Flowers, A., Costello, M. R., & Small, V. (1975). Flowers-Costello tests of central auditory abilities. Dearborn, MI: Perceptual Learning Systems.
- Friel-Patti, S. (1999). Clinical decision-making in the assessment and intervention of central auditory processing disorders. *Language, Speech, and Hearing Services in Schools*, 30(4), 345-352.
- Gelfand, S. A. (1998). Optimizing the reliability of speech recognition scores. *Journal of Speech, Language, and Hearing Research*, 41(5), 1088-1102.
- Gibbins, J. (2017). *The development of a new technique for the normalisation of the University of Canterbury adaptive speech test-filtered words (UCAST-FW)*. Retrieved from <https://ir.canterbury.ac.nz/handle/10092/15177>
- Goodman, A. (1965). Reference zero levels for pure-tone audiometer. *Asha*, 7(262), 1.
- Gordon, L. (2015). 'Rich' and 'poor' schools revisited. *New Zealand Journal of Educational Studies*, 50(1), 7-21.
- Hackett, T. A. (2009). *Organization of the central auditory pathways in nonhuman primates and humans*. San Diego, CA: Plural Publishing Inc.
- Hackett, T. A., Smiley, J. F., Ulbert, I., Karmos, G., Lakatos, P., de la Mothe, L. A., & Schroeder, C. E. (2007). Sources of somatosensory input to the caudal belt areas of auditory cortex. *Perception*, 36(10), 1419-1430.
- Hallett, T., & Proctor, A. (1996). Maturation of the central nervous system as related to communication and cognitive development. *Infants & Young Children*, 8(4), 1-15.

- Heidtke, U. J. (2010). *Diagnosis of auditory processing disorder in children using an adaptive filtered speech test* (Masters of Audiology), University of Canterbury, Christchurch, New Zealand.
- Hornsby, B., & Mueller, G. (2013). *Monosyllabic word testing: Five simple steps to improve accuracy and efficiency*. Retrieved from <http://www.audiologyonline.com/articles/word-recognition-testing-puzzling-disconnect-11978>.
- Jamshidian, M., & Jalal, S. (2010). Tests of homoscedasticity, normality, and missing completely at random for incomplete multivariate data. *Psychometrika*, 75(4), 649-674.
- Jeffress, L. A. (1948). A place theory of sound localization. *Journal of Comparative and Physiological Psychology*, 41(1), 35.
- Ji, F., Xi, X., Chen, A.-t., Ying, J., Wang, Q.-j., & Yang, S.-M. (2011). Development of a Mandarin monosyllable test material with homogenous items (I): Homogeneity selection. *Acta Oto-Laryngologica*, 131(9), 962-969.
- Jones, E. G. (2003). Chemically defined parallel pathways in the monkey auditory system. *Annals of the New York Academy of Sciences*, 999(1), 218-233.
- Kaernbach, C. (2001). Adaptive threshold estimation with unforced-choice tasks. *Perception and Psychophysics*, 63(8), 1377-1388.
- Keith, R. W. (1981a). *Audiological and auditory-language tests of central auditory function* (Vol. 30). Houston: TX, College Hill Press Houston.
- Keith, R. W. (2009). *SCAN-3 for children: Tests for auditory processing disorders*. New York, NY: Pearson.

- Keith, R. W. (2000). Development and standardization of SCAN-C test for auditory processing disorders in children. *Journal of the American Academy of Audiology*, 11(8), 438-445.
- Keith, R. W. (1994). *SCAN-A: A test for auditory processing disorders in adolescents and adults*. Psychological Corporation.
- Keith, R. W. (1981b). Audiological and auditory-language tests of central auditory function. In *Central auditory and language disorders in children* (pp. 61-76). Houston, TX: College Hill Press.
- Kim, Kim, J., Park, I.-Y., Jung, J. Y., Suh, M.-W., & Oh, S.-h. (2018). Effects of transient auditory deprivation during critical periods on the development of auditory temporal processing. *International Journal of Pediatric Otorhinolaryngology*, 104, 66-71.
- Kim, K.-j., & Ahn, H. (2008). A recommender system using GA K-means clustering in an online shopping market. *Expert systems with Applications*, 34(2), 1200-1209.
- Kral, A. (2013). Auditory critical periods: A review from system's perspective. *Neuroscience*, 247, 117-133.
- Krishnamurti, S. (2007). Monaural low-redundancy speech tests. In F. E. Musiek and G. D. Chermak (Eds.), *Handbook of (central) auditory processing disorder. Auditory neuroscience and diagnosis*. (Vol. 1). San Diego, CA: Plural Publishing.
- Levitt, H., & Rabiner, L. R. (1967). Use of a sequential strategy in intelligibility testing. *The Journal of the Acoustical Society of America*, 42(3), 609-612.

- Liberalesso, P. B. N., D'Andrea, K. F. K., Cordeiro, M. L., Zeigelboim, B. S., Marques, J. M., & Jurkiewicz, A. L. (2012). Effects of sleep deprivation on central auditory processing. *BMC Neuroscience*, 13(1), 83.
- Luce, P. A., & Pisoni, D. B. (1998). Recognizing spoken words: The neighborhood activation model. *Ear and Hearing*, 19(1), 1.
- Martin, F. N., & Clark, J. G. (1977). Audiologic detection of auditory processing disorders in children. *Journal of the American Audiology Society*, 3(3), 140-146.
- McFarland, D. J., & Cacace, A. T. (1995). Modality specificity as a criterion for diagnosing central auditory processing disorders. *American Journal of Audiology*, 4(3), 36-48.
- McGaffin, A. J. (2007). *Development of a monosyllabic adaptive speech test for the identification of central auditory processing disorder* (Masters of Audiology), University of Canterbury, Christchurch, New Zealand.
- Ministry of Health. (2014). *National Vision and Hearing Screening Protocols*. Retrieved from: <https://www.health.govt.nz/system/files/documents/publications/national-vision-hearing-screening-protocols-v3.pdf> [Accessed 9 Oct. 2018].
- Murray, S. L. (2012). *Development of the New Zealand stimuli for the University of Canterbury Adaptive Speech Test-Filtered Words (UCAST-FW)*. Retrieved from <https://ir.canterbury.ac.nz/handle/10092/7131>
- Musiek, F. E., Geurkink, N. A., & Kietel, S. A. (1982). Test battery assessment of auditory perceptual dysfunction in children. *The Laryngoscope*, 92(3), 251-257.
- Myklebust, H. R. (1954). *Auditory disorders in children: A manual for differential diagnosis*. Grune & Stratton.

- Nagao, K., Riegner, T., Padilla, J., Greenwood, L. A., Loson, J., Zavala, S., & Morlet, T. (2016). Prevalence of auditory processing disorder in school-aged children in the mid-Atlantic region. *Journal of the American Academy of Audiology*, 27(9).
- Neumann, K., Baumeister, N., Baumann, U., Sick, U., Euler, H. A., & Weißgerber, T. (2012). Speech audiometry in quiet with the Oldenburg Sentence Test for Children. *International Journal of Audiology*, 51(3), 157-163.
- Noordhoek, I. M., Houtgast, T., & Festen, J. M. (2000). Measuring the threshold for speech reception by adaptive variation of the signal bandwidth. II. Hearing-impaired listeners. *The Journal of the Acoustical Society of America*, 107(3), 1685-1696.
- O'Beirne, G. A., McGaffin, A. J., & Rickard, N. A. (2012). Development of an adaptive low-pass filtered speech test for the identification of auditory processing disorders. *International Journal of Pediatric Otorhinolaryngology*, 76(6), 777-782.
- O'Connor, P. (1990). Normative data: Their definition, interpretation, and importance for primary care physicians. *Family Medicine*, 22(4), 307-311.
- Pannese, A., Grandjean, D., & Frühholz, S. (2015). Subcortical processing in auditory communication. *Hearing Research*, 328, 67-77.
- Picard, M., & Bradley, J. (2001). Revisiting speech interference in classrooms: Revisando la interferencia en el habla dentro del salón de clases. *International Journal of Audiology*, 40(5), 221-244. <http://dx.doi.org/10.3109/00206090109073117>
- Ponton, C. W., Eggermont, J. J., Kwong, B., & Don, M. (2000). Maturation of human central auditory system activity: evidence from multi-channel evoked potentials. *Clinical Neurophysiology*, 111(2), 220-236.

Poremba, A., Malloy, M., Saunders, R. C., Carson, R. E., Herscovitch, P., & Mishkin, M. (2004). Species-specific calls evoke asymmetric activity in the monkey's temporal poles. *Nature*, 427(6973), 448.

Purdy, S. C., Kelly, A. S., & Davies, M. G. (2002). Auditory brainstem response, middle latency response, and late cortical evoked potentials in children with learning disabilities. *Journal of the American Academy of Audiology*, 13(7), 367-382.

Rees, A. (2009). Medial Geniculate Body. In *Encyclopedia of Neuroscience* (pp. 2275-2279). Springer, Berlin, Heidelberg.

Rickard, N. A., Heidtke, U. J., & O'Beirne, G. A. (2013). Assessment of auditory processing disorder in children using an adaptive filtered speech test. *International Journal of Audiology*, 52(10), 687-697.

Rintelmann, W. (1985). *Monaural speech tests in the detection of central auditory disorders*. Baltimore, Marland: Williams and Wilkins.

Romand, R., & Avan, P. (1997). *Anatomical and functional aspects of the cochlear nucleus*. New York, NY: Oxford University Press.

Ruscetta, M. N., Palmer, C. V., Durrant, J. D., Grayhack, J., & Ryan, C. (2005). Validity, internal consistency, and test/retest reliability of a localization disabilities and handicaps questionnaire. *Journal of the American Academy of Audiology*, 16(8), 585-595.

Salkind, N. J. (2010). *Encyclopedia of research design* (Vol. 1). Thousand Oaks, CA: Sage.

- Schochat, E., & Musiek, F. E. (2006). Maturation of outcomes of behavioral and electrophysiologic tests of central auditory function. *Journal of Communication Disorders*, 39(1), 78-92.
- Sharma, M., & Purdy, S. C. (2013). *Management of auditory processing disorder for school-aged children: Applying the ICF (International Classification of Functioning, Disability and Health) framework* (Vol. 2). Queensland, Australia: Plural Publishing.
- Sharma, A., Kraus, N., McGee, T. J., & Nicol, T. G. (1997). Developmental changes in P1 and N1 central auditory responses elicited by consonant-vowel syllables. *Clinical Neurophysiology*, 104(6), 540-545.
- Shuttleworth, M. (2009). Counterbalanced measures design. Retrieved from *Experiment Resources*. Accessed 2nd May.
- Sincock, B. P. (2008). *Clinical applicability of adaptive speech testing: a comparison of the administration time, accuracy, efficiency and reliability of adaptive speech tests with conventional speech audiometry*. Retrieved from <https://ir.canterbury.ac.nz/handle/10092/2157>
- Sowell, E., Peterson, B., Thompson, P., Welcome, S., Henkenius, A., & Toga, A. (2003). Mapping cortical change across the human life span. *Nature Neuroscience*, 6(3), 309-315. <http://dx.doi.org/10.1038/nn1008>
- Teatini, G. P. (1970). Sensitized speech tests: Results in normal subjects. *Danavox Foundation, Odense, Denmark*.
- The British Society of Audiology (2018). *Position statement and practice guidance auditory processing disorder (APD)*. Retrieved from <http://www.thebsa.org.uk/bsa-groups/group-apdi/>

- Willeford, J. (1977). *Assessing central auditory behavior in children: A test battery approach*. New York, NY: Grune and Stratton.
- Wilson, W. J., & Arnott, W. (2013). Using different criteria to diagnose (central) auditory processing disorder: How big a difference does it make? *Journal of Speech, Language, and Hearing Research*, 56(1), 63-70.
- Wilson, W. J., Heine, C., & Harvey, L. A. (2004). Central auditory processing and central auditory processing disorder: Fundamental questions and considerations. *The Australian and New Zealand Journal of Audiology*, 26(2), 80.
- Wunderlich, J. L., Cone-Wesson, B. K., & Shepherd, R. (2006). Maturation of the cortical auditory evoked potential in infants and young children. *Hearing Research*, 212(1-2), 185-202.
- Zealand, S. N. (2012). *Demographic trends 2010*. Retrieved from http://archive.stats.govt.nz/browse_for_stats/population/estimates_and_projections/demographic-trends-2010.aspx

7. Appendices

Appendix A: Ethical Approval



HUMAN ETHICS COMMITTEE

Secretary
Telephone: +64 03 369 4588, Extn 94588
Email: human-ethics@canterbury.ac.nz

Ref: 2018/04/ERHEC-LR Amendment 1

25 September 2018

Marie Lay and Justin Yau
Communication Disorders
UNIVERSITY OF CANTERBURY

Dear Marie and Justin

Thank you for your request for an amendment to your research proposal “Development of the University of Canterbury Paediatric Auditory-Visual Matrix Sentence Test: Sentence Equivalence and Normative Data and Normative Data for the UCAST-FW Test of APD in Children to Produce Correction Factors for Adjustment to Maturation Effect” as outlined in your email dated 20th September 2018. I am pleased to advise that this amendment has been considered and approved by the Educational Research Human Ethics Committee.

Please note that should circumstances relevant to this current application change you are required to reapply for ethical approval.

If you have any questions regarding this approval, please advise.

We wish you well for your continuing research.

Yours sincerely

PP Dr Patrick Shepherd
Chair
Educational Research Human Ethics Committee

Please note that ethical approval relates only to the ethical elements of the relationship between the researcher, research participants and other stakeholders. The granting of approval by the Educational Research Human Ethics Committee should not be interpreted as comment on the methodology, legality, value or any other matters relating to this research.

F E S

Appendix B: Recruitment and Consent

B1: Information sheet & consent form given to each participant's parent/guardian prior to testing (page 1 of 4)

Department of Communication Disorders
Phone: +64 3 369 4827
Email: fiona.bellett@canterbury.ac.nz
www.cmds.canterbury.ac.nz



Parent/Guardian Consent Form for Child's Participation in Research Studies

Normative Data for the UCAMST-P; Normative Data for the UCAST-FW

I have read and understand the Information Sheet and Parent Consent Form. I will be given a copy to keep and have had the opportunity to ask questions.

The researcher has agreed not to reveal my child's and my identity and personal details if information about this project is published or presented in any public form.

I agree that research data gathered in this study may be published and used in future studies. I provide consent for this publication and the re-use of the data with the understanding that my child's and my name or other identifying information will not be used.

I understand that my child's participation in this project is voluntary and that he/she is free to withdraw at any time without penalty. Withdrawal of participation will also include the withdrawal of any information we have provided should this remain practically achievable.

I understand that all data collected for the study will be kept confidential to the researchers and supervisors (contact information displayed on page 2). I understand that all data will be kept in locked and secure facilities and/or in password protected electronic form and will be destroyed after five years.

I understand that I will receive information about my child's hearing and may receive referral for further diagnostic assessment if an unexpected hearing loss is found.

I understand that I can contact the researchers or supervisors for further information. If I have any complaints, they may be addressed to The Chair, Educational Research Human Ethics Committee, University of Canterbury, Private Bag 4800, Christchurch, Email: human-ethics@canterbury.ac.nz

I understand that this project has been reviewed **and approved** by the Department of Communication Disorders, University of Canterbury. On this basis, I give consent for my child (named below) to participate in this research project.

I would like to receive a copy of my child's
hearing screen (please tick one):

Yes ☐ No ☐

I agree to be contacted in future, for my child's
participation in ongoing research (please tick one):

Yes ☐ No ☐

If yes, please provide a contact email and/or postal address below:

.....

By signing below, I give consent for my child to participate in this research project.

B1: Information sheet & consent form given to each participant's parent/guardian prior to testing (page 2 of 4)

MY CHILD'S NAME (please print):.....

MY NAME (please print):

Signature

Date

Note: All parties signing the Consent Form must date their own signature. Please return the consent form to the researcher before your child actively participates in this research.

With thanks,

Marie Lay
2nd year MAud Student
Department of Communication Disorders
University of Canterbury
Email: msl55@uclive.ac.nz
Phone: 021 029 68881

Justin Yau
2nd year MAud Student
Department of Communication Disorders
University of Canterbury
Email: jjy26@uclive.ac.nz
Phone: 0277462856

Greg O'Beirne
Primary Research Supervisor & Associate Professor in Audiology
Department of Communication Disorders University of Canterbury
Email: gregory.obeirne@canterbury.ac.nz
Phone: +64 3 369 4313

Suzanne Purdy
Secondary Research Supervisor & Head of School
Psychology
The University of Auckland
Email: sc.purdy@auckland.ac.nz
Phone: +64 9 923 2073

Rebecca Kelly-Campbell
Secondary Research Supervisor & Senior Lecturer in Audiology
Department of Communication Disorders
University of Canterbury
Email: rebecca.kelly@canterbury.ac.nz
Phone: +64 3 369 4519

B1: Information sheet & consent form given to each participant's parent/guardian prior to testing (page 3 of 4)

Department of Communication Disorders
Phone: +64 3 369 4827
Email: fiona.bellett@canterbury.ac.nz
www.cmds.canterbury.ac.nz



Information Sheet

Full Project Titles:

Normative Data for the UCAMST-P; Normative data for the UCAST-FW

Principal Researchers: Marie Lay and Justin Yau, MAud students (2nd year)
Department of Communication Disorders

Research Supervisor: Associate Professor Greg O'Beirne
Department of Communication Disorders

Associate Supervisors: Dr. Rebecca Kelly-Campbell, Senior Lecturer
Department of Communication Disorders

Professor Suzanne Purdy, Head of School
Psychology Department, University of Auckland

This study is part of two projects; one project aims to further develop a paediatric speech test in New Zealand English to supplement other tests typically used to assess hearing, and the other aims to further develop an auditory processing speech test to supplement tests currently used to diagnose auditory processing disorder (APD). This study is being carried out as part of two Master of Audiology thesis projects.

The study contains two parts, both of which aim to gather information regarding the normal range of results we could expect in the general population.

The test will take place at the University of Canterbury (either in the Audiology clinics of the Department of Communication Disorders, or the Audiology laboratory in Rutherford 801), or the school the child attends (in a classroom set aside for testing).

To be eligible to participate, your child must:

- be 6 - 12 years of age
- have normal hearing
- have no current middle ear pathology (i.e. ear infections or surgeries)
- have no history of neurological disease or impairment

Prior to any testing, you will be given a short questionnaire focused on your child's ear health and family context. Your child's ears will then be examined, and they will undergo a hearing check (if you have not provided an audiologist-completed audiogram dated within six months). In the event of an unexpected diagnosis of a hearing loss, a full

B1: Information sheet & consent form given to each participant's parent/guardian prior to testing (page 4 of 4)

audiological assessment will be offered at the University of Canterbury Speech and Hearing Clinic free of charge. If you choose to follow up with your GP or an external audiologist, this will be at your own expense.

Following the hearing check, your child will complete two sentence tests. In one test your child will hear short sentences being read aloud in noise. The words will change in loudness and may at times become difficult for your child to hear. After each sentence has been read, your child will be asked to repeat what they thought they heard. In the other test your child will hear words being read aloud without noise, but clarity of words will progressively worsen. After each word has been heard, your child will be asked to select one of four pictures on a tablet, corresponding to the word they think they heard. These two tests should take no more than 45 minutes. Breaks will be provided as needed, and testing may be spread over more than one session where appropriate.

We are happy to answer any queries you may have. Our phone and email details are provided in case you have any questions either now or at a later date. As a token of our appreciation you will receive an honorarium of a \$10 voucher, as well as the hearing check for your child mentioned above.

We have provided a consent form for you to sign on behalf of your child prior to their participation in this study. If you would like a copy of your child's hearing screening results and/or be contacted for your child's participation in future research, you may indicate this on the consent form. Your child will also be given an assent form to fill out prior to testing, if they still wish to be involved. Signing the consent form indicates your understanding that the data collected in this study will be confidential, and only viewed by people directly involved in this study (those listed below). All identifying information will be kept in secure facilities and in password protected electronic form. Participation is voluntary and your child has the right to withdraw at any time, without penalty. If your child withdraws, I will remove all of the information relating to you and your child.

This project has been reviewed and approved by the Department of Communication Disorders, University of Canterbury. Complaints may be addressed to The Chair, Educational Research Human Ethics Committee, University of Canterbury, Pr
anterbury.ac.nz

W Marie Lay
2nd year MAud Student
Department of Communication Disorders
University of Canterbury
Email: msl55@uclive.ac.nz
Phone: 021 029 68881

Justin Yau
2nd year MAud Student
Department of Communication Disorders
University of Canterbury
Email: jjy26@uclive.ac.nz
Phone: 0277462856

Greg O'Beirne
Primary Research Supervisor & Associate Professor in
Audiology
Department of Communication Disorders University
of Canterbury
Email: gregory.obeirne@canterbury.ac.nz
Phone: +64 3 369 4313

Suzanne Purdy
Secondary Research Supervisor & Head of School
Psychology
The University of Auckland
Email: sc.purdy@auckland.ac.nz
Phone: +64 9 923 2073

Rebecca Kelly-Campbell
Secondary Research Supervisor & Senior Lecturer in
Audiology
Department of Communication Disorders
University of Canterbury
Email: rebecca.kelly@canterbury.ac.nz
Phone: +64 3 369 4519

B2: Information sheet and assent form for 11-12 year old participants (page 1 of 2)

Department of Communication Disorders
Phone: +64 3 369 4827
Email: fiona.bellett@canterbury.ac.nz
www.cmds.canterbury.ac.nz



INFORMATION SHEET For 11-12 year olds

Why are we meeting with you?

We are doing a “research study”, which is when investigators collect information to learn more about something. Marie and Justin are trying to learn more about how well children can complete some listening games. After we tell you about our study, we will ask if you'd like to be in it or not. Your parent or the person taking care of you knows that we asked you to be part of this study.

Why are we doing this study?

We want to find out how well kids with good hearing can finish three different listening games. This study will help make the listening games better at testing how good a child's hearing is.

What will you do in this study?

If you agree, we will ask you to complete these four things:

1. Marie or Justin will look in your ears with a little torch.
2. Game 1: You will wear headphones and listen for whistle sounds. We will ask you to push a button whenever you hear the whistle sounds.
3. Game 2: You will listen to short sentences, with noise playing. We will ask you to say to us what you hear.
4. Game 3: You will listen to words that might sound muffled. We will ask you to choose the picture of the word you heard on an iPad.



This should all take about 45 minutes.

Do I have to be in the study?

No, you don't. No one will be mad at you if you say no. If you don't want to be in this study, just tell us, or your parent, or the person who looks after you. If you do want to be in the study, tell us that. And, remember, you can say yes now and change your mind later. It's up to you.

What if there is a problem?

If you are worried about the study or have any questions you can ask your parent or the person who looks after you. You can also ask Justin or Marie if you want to.



B2: Information sheet and assent form for 11-12 year old participants (page 2 of 2)



**ASSENT FORM
For 11-12 year olds**



Participant's Name: _____
(Full Name in BLOCK CAPITALS)

Date of Birth: _____
(Month/Year)

Please circle all you agree with:

Have you read this form (or had it read to you)?	Yes/No
Has the investigator explained this study to you?	Yes/No
Do you understand what this study is about?	Yes/No
Have you asked all the questions you want?	Yes/No
Are you happy to take part in this research study?	Yes/No

If any answers are “no” or you **don't** want to take part, **don't** sign your name!

If you **do** want to take part in this study, please write your name and today's date below.

You will be given a copy of this signed form.

Participant's Full Name: _____

Participant's Signature for Assent: _____

Date: _____

Statement of Person Obtaining Informed Assent

I, the undersigned, have fully explained the details of this research study to the participant named above.

Name

Signature

Date



B3: Information sheet and assent form for 6-10 year old participants (page 1 of 2)

Department of Communication Disorders
Phone: +64 3 369 4827
Email: fiona.bellett@canterbury.ac.nz
www.cmds.canterbury.ac.nz



INFORMATION SHEET For 6-10 year olds



Marie and Justin are doing a project to find out how well children can play two different listening games. These games tell us how good a child's hearing is.



If I take part in this project,

- 1) We will look in your ears with a little torch
- 2) You will play 3 different listening games, with headphones on:

A close-up illustration of a hand with a red button being pushed.	Game 1: You will push a button when you hear a whistle sound.
A cartoon illustration of a boy and a girl standing and talking to each other.	Game 2: You will listen to short sentences, with some noise in the background. We will ask you to repeat what you heard.
A black iPad showing a home screen with various app icons.	Game 3: You will listen to words that might sound muffled. We will ask you to select the picture of the word on an iPad.



I can say no if I don't want to play these games. I can tell my parent or the person looking after me if I don't want to play. I can tell Marie or Justin or my teacher as well. I can change my mind later, even if I say yes now.



I can ask my teacher, parent, the person looking after me, Marie or Justin if I have any problems or questions.

My parent or the person looking after me knows I have been asked to be part of this study.

B3: Information sheet and assent form for 6-10 year old participants (page 2 of 2)

Department of Communication Disorders
Phone: +64 3 369 4827
Email: fiona.bellett@canterbury.ac.nz
www.cmds.canterbury.ac.nz



ASSENT FORM
For 6-10 year olds

Marie and Justin's project about listening games has been explained to me. I know if I agree, Marie or Justin will look in my ears, and I will play three different listening games. I know I don't have to be part of it if I don't want to. I know that if I change my mind about playing the games, I can stop anytime I want to.

If I have any questions I can ask my teacher, mum, dad, or the person looking after me. I can also ask Marie or Justin.



I am happy for Marie or Justin to look in my ears and play the listening games, so I have coloured in the happy face.



I don't want Marie or Justin to look in my ears or play the listening games, so I have coloured in the sad face.

My full name:

Please give this back to your teacher now.



B4: Information sheet and consent form for the participant's teacher; utilised in preparation for testing in the primary schools (page 1 of 3)

Department of
Communication Disorders



Study Information for School Teacher

Project Titles: Normative Data for the UCAMST-P and
Normative data for the UCAST-FW

Testing dates: Term 3
Monday, Tuesday, 8.30am-12pm at Hoon Hay School

We would like to thank you for your cooperation and willingness to accommodate our research. Below is information to outline the roles and responsibilities for both you as the teacher of the child participant and Marie & Justin as the researchers.

This study is part of two projects; one project aims to further develop a paediatric speech test in New Zealand English to supplement other tests typically used to assess hearing, and the other aims to further develop an auditory processing speech test to supplement tests currently used to diagnose auditory processing disorder (APD). This study is being carried out as part of two Master of Audiology thesis projects.

The study contains two parts, both of which aim to gather information regarding the normal range of results we could expect in the general population.
To be eligible to participate, a child must:

- be 6 - 12 years of age
- have normal hearing
- have no current middle ear pathology (i.e. ear infections or surgeries)
- have no history of neurological disease or impairment

We ask that you as the teacher could email the information sheet and parent/guardian consent form to parents/guardians of your students who meet the above criteria and return the completed consent forms to us. If a parent/guardian is unable to complete the written consent form but is happy for their child to participate, we ask that you as the teacher could sign the "verbal consent from the parent/guardian" section of the consent form.

For each participant, you as their teacher will be given a short questionnaire focused on the student's listening behavior in the classroom and their reading, writing, language, and behavioural development. If you could complete and return the questionnaires to either Justin or Marie, this would be greatly appreciated.

B4: Information sheet and consent form for the participant's teacher; utilised in preparation for testing in the primary schools (page 2 of 3)

Roles and Responsibilities:

It is expected that you will:

- Identify appropriate students for participation in this study and return parental consent forms to Justin or Marie

It is NOT expected that schools will:

- Choose students who do not meet the inclusion criteria, as far as they are aware
- Be present for assessment sessions. You may wish to observe sessions for your own interest

It is expected that Marie and/or Justin will:

- Sign in and out of the visitor's book at _____ School daily
- Ensure consent and assent for assessment and intervention has been obtained
- Demonstrate best practise for assessment and intervention
- Demonstrate effective communication skills: Keeping parents, teachers and other relevant staff informed

Contact persons:

Marie Lay

2nd year MAud Student

Department of Communication Disorders, University of Canterbury

Email: msl55@uclive.ac.nz

Phone: 021 029 68881

Justin Yau

2nd year MAud Student

Department of Communication Disorders, University of Canterbury

Email: jjy26@uclive.ac.nz

Phone: 0277462856

Greg O'Beirne

Primary Research Supervisor & Associate Professor in Audiology

Department of Communication Disorders, University of Canterbury

Email: gregory.obeirne@canterbury.ac.nz

Phone: +64 3 369 4313

B4: Information sheet and consent form for the participant's teacher; utilised in preparation for testing in the primary schools (page 3 of 3)

Department of Communication Disorders
Phone: +64 3 369 4827
Email: fiona.bellett@canterbury.ac.nz
www.cmds.canterbury.ac.nz



School Teacher Consent Form for Student's Participation in Research Studies

Normative Data for the UCAMST-P; Normative Data for the UCAST-FW

I have read and understand the Study Information Sheet for School Teacher and School Teacher Consent Form. I will be given a copy to keep and have had the opportunity to ask questions.

The researcher has agreed not to reveal my students' and my identity and personal details if information about this project is published or presented in any public form.

I agree that research data gathered in this study may be published and used in future studies. I provide consent for this publication and the re-use of the data with the understanding that my students' and my name or other identifying information will not be used.

I understand that my students' participation in this project is voluntary and that he/she is free to withdraw at any time without penalty. Withdrawal of participation will also include the withdrawal of any information we have provided should this remain practically achievable.

I understand that all data collected for the study will be kept confidential to the researchers and supervisors (contact information displayed on page 2). I understand that all data will be kept in locked and secure facilities and/or in password protected electronic form and will be destroyed after five years.

I understand that I can receive information about my students' hearing if I choose to inquire and their parents/guardians may receive referral for further diagnostic assessment if an unexpected hearing loss is found.

I understand that I can contact the researchers or supervisors for further information. If I have any complaints, they may be addressed to The Chair, Educational Research Human Ethics Committee, University of Canterbury, Private Bag 4800, Christchurch, Email: human-ethics@canterbury.ac.nz

I understand that this project has been reviewed **and approved** by the Department of Communication Disorders, University of Canterbury. On this basis, I give consent to participate in this research project.

By signing below, I give consent to participate in this research project.

MY NAME (please print):

Signature
.....

Date

Note: All parties signing the Consent Form must date their own signature. Please return the consent form to either Marie Lay or Justin Yau before your child actively participates in this research.

B5: Advertisement email initiation to parents for Team Tamariki recruitment channel

VOLUNTEERS NEEDED!

to help develop two NZ paediatric speech tests

We are looking for participants who:

- 👂 are **between 6 and 12 years old**
- 👂 have **normal hearing**
- 👂 have **no current middle ear pathology** (i.e. ear infection)
- 👂 have **no history of neurological impairment**

We are developing two exciting new speech tests. One test will be used to diagnose hearing loss, and the other will help diagnose auditory processing disorder, in New Zealand children.

This study will take place at the University of Canterbury Speech and Hearing Clinic at Creyke Road, Ilam, or at the school the child attends, in a classroom set aside for testing.

Prior to any testing, you will be given a short questionnaire focused on your child's ear health and family context.

Your child would be needed for one 45 minute session, during this time your child will:

- **receive a free hearing check**
- **help to develop two exciting new paediatric speech tests for use in NZ clinics**
- **get a first hand look at these new speech tests**

As a token of our appreciation you will receive a honarium of a \$10 voucher.

For more information, or to be involved in this project, please contact
Marie Lay at marie.lay@pg.canterbury.ac.nz or text/call **021 029 68881** OR
Justin Yau at justin.yau@pg.canterbury.ac.nz or text/call **0277462856**.

This project has been reviewed and approved by the University of Canterbury Human Ethics Committee